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RETENTION AND APPLICATION OF SATURN EXPERIENCES TO FUTURE PROGRAMS

By W. David Brown and Nancy Milly
Quality and Reliability Assurance Laboratory

September 14, 1971 (Revised edition)

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

NOTICE

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16. Abstract

Presented in this report are 422 significant Unsatisfactory Condition Reports and other problems reaching senior contractor/MSFC management level attention, experienced on the Saturn program. Significant Unsatisfactory Condition problems are defined as those problems which could cause loss of life, loss of mission, or launch scrub. Fifty-two new inspection techniques, developed or refined during the Saturn program, are also identified.

The purpose of this report is to summarize the experience and practical benefits of the Saturn program for dissemination and use on future programs.

Three indices are provided for locating specific problems by hardware type, problem type, and physical condition.

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ABBREVIATIONS

AC	Alternating Current
AMP	Ampere
APS	Auxiliary Propulsion System
ASI	Augmented Spark Igniter
ATOLL	Acceptance, Test or Launch Language
CDDT	Count Down Demonstration Test
CdS	Cadmium Sulfide
CdSe	Cadmium Selenide
CRES	Corrosion Resistant Steel
DC	Direct Current
ECA	Electrical Control Assembly
ECS	Environmental Control System
E. O.	Engineering Order
EQA	Equipment Quality Analysis
FACI	First Article Configuration Inspection
FEP	Fluorinated Ethylene Prophylene
FOT	Fitting Optical Targets
GH_2	Gaseous Hydrogen
GN_2	Gaseous Nitrogen
GSE	Ground Support Equipment
H_2O	Water
HI-REL	High Reliability
IMV	Ignition Monitor Valve
IR	Infrared Radiation
KSC	Kennedy Space Center
LH_2	Liquid Hydrogen
LOX	Liquid Oxygen
LSC	Linear Shaped Charge
MD	Mass Drop-Off
MSFC	Marshall Space Flight Center
NDT	Non-Destructive Test
O_2	Oxygen
PAT	Production Acceptance Tests
P.C.	Printed Circuit
PC-EL	Photoconductor-Electroluminescent
P.U.	Propellant Utilization
Q.D.	Quick Disconnect
QMT	Quality Maintenance Testing
RFI	Radio Frequency Interference

SCCM	Standard Cubic Centimeters/Minute
SCFM	Standard Cubic Feet/Minute
SCIM	Standard Cubic Inches/Minute
SCR	Silicon Controlled Rectifier
SEN	Single-Edge Notched
SOFI	Spray-On Foam Insulation
SPDT	Single Pole Double Throw
TIG	Tungsten Inert Gas
UCR	Unsatisfactory Condition Report
UER	Unplanned Event Record
VDC	Volts, Direct Current
VRMS	Volts, Root-Mean-Square
ZnO	Zinc Oxide

TECHNICAL MEMORANDUM TM X-64574

RETENTION AND APPLICATION OF SATURN EXPERIENCES TO FUTURE PROGRAMS

SUMMARY

A total of 1, 178 Saturn significant Unsatisfactory Condition Reports (UCR's), (approximately 95 percent of which occurred during or subsequent to Post-Manufacturing Checkout), and 86 other problems that reached senior contractor/MSFC management attention, were reviewed to formulate this document. Significant UCR's are those reported conditions that could cause loss of life, loss of mission, or a launch scrub. All duplications and unverified failures were eliminated. Of the resulting 422 problem entries, 187 or 44 percent were electrical problems, and 235 or 56 percent were mechanical problems. The problems in each section were collated and indexed by type of hardware. Connectors experienced the greatest number of problems in the electrical section and accounted for 18 percent of the reported problems, while relays and switches were next with 15 percent. In the mechanical section, valves and modules experienced the largest number of problems and accounted for 34 percent of the reported problems.

The problems were indexed into five major categories of problem orientation. Overall, 29 percent are Design oriented problems, 25 percent are Human Error, 4 percent are Maintenance, 21 percent are Manufacturing, and 21 percent are Procedures problems. In the electrical section, Design accounted for 26 percent of the problems, Human Error 30 percent, Maintenance 2 percent, Manufacturing 24 percent, and Procedures 18 percent. In the mechanical section, Design accounted for 31 percent of the problems, Human Error 20 percent, Maintenance 6 percent, Manufacturing 19 percent, and Procedures 24 percent.

The problems were also indexed according to the hardware physical condition. In the electrical section, the physical condition of contaminated or corroded accounted for 14 percent of the problems and shorted accounted for 9 percent. Each of the other physical conditions in the electrical problem section accounted for 7 percent or less. In the mechanical section, bent, chipped, cracked, or broken accounted for 20 percent of the problems while contaminated, corroded, or eroded accounted for 18 percent. Each of the other physical conditions were 10 percent or less.

Fifty-two new inspection techniques are identified that were either developed or refined during the Saturn program. The techniques range from individual component inspection to overall system and end item inspections for both hardware and software.

INTRODUCTION

This document has been prepared to summarize the problems encountered and new techniques developed on the Saturn program, and to summarize the experiences and practical benefits obtained for dissemination and use on future programs. A total of 1,264 Saturn significant Unsatisfactory Condition Reports (UCR's) and other problem reports were reviewed to formulate this document.

The document is divided into three major sections: an electrical problem section, a mechanical problem section, and a new technique section. Each problem section is prefaced by three indices:

1. Hardware Index - Classifies the problems by type of hardware such as valves, switches, etc.

2. Problem Index - Lists the problems with the hardware by the following types of problems:

Design	- Problems resulting from inadequate design.
Human Error	- Problems resulting from human error, workmanship, etc.
Maintenance	- Problems resulting from the lack of maintenance/preventive maintenance and inadequate processing controls subsequent to manufacture.
Manufacturing	- Problems resulting from the manufacturing process, excluding procedural and human error problems.
Procedures	- Problems resulting from deficient procedures.

3. Condition Index - Denotes the physical condition of the hardware after problem occurrence.

Each individual entry in the electrical and mechanical problem summaries as referenced by the indices contains the following information:

Item Number	Problem Description	Problem Effect
Hardware Nomenclature	Problem Cause	Remarks/ Suggestions
Reference Code		

All duplication has been eliminated in the document in that items with the same hardware nomenclature, problem, and cause appear only once; however, where the problem and/or cause is not the same, the item is again identified. The entries are collated into hardware families or similar hardware families and it should be noted that the figures and numbers reflected on the hardware, problem, and condition graphs relate only to the contents of this document.

Contained in section three of this document are fifty-two new inspection techniques that were developed or refined during the Saturn program.

The reference codes listed below are for assistance in obtaining more detailed information on any problem or technique identified in this document.

Code	Office Symbol	Mailing Address	Telephone No.
A	PM-MA-Q	P. O. Box 26078, New Orleans, Louisiana 70126	504/255-3401
B	S&E-QUAL-E/ NR/SD	12214 Lakewood Boulevard, Downey, California 90241	213/594-3781
C	S&E-QUAL-E/ MDAC	5301 Bolsa Avenue, Huntington Beach, California 92647	213/896-1224
D	S&E-QUAL-E/ RKDN	6633 Canoga Avenue, Canoga Park, California 91303	213/884-3306
E	S&E-QUAL-E/IBM	150 Sparkman Drive, Building #2 Huntsville, Alabama 35805	205/895-1193
F	S&E-QUAL-QT/ MSFC	Marshall Space Flight Center, Building #4708, Huntsville, Alabama 35812	205/453-3986
G	S&E-QUAL-AR/ MSFC	Marshall Space Flight Center, Building #4708, Huntsville, Alabama 35812	205/453-1474
H	S&E-QUAL-PC/ MSFC	Marshall Space Flight Center, Building #4708, Huntsville, Alabama 35812	205/453-4740

CONCLUSIONS AND RECOMMENDATIONS

It is not the intent of this handbook to make conclusions and recommendations concerning design changes, procedural changes, etc.; however, it is recommended that this data be used in future programs to minimize occurrence of similar problems. This document can have broad application in future space activities - from the designer making a part selection for a specific application to the test engineer or technician in the identification of a particular failure cause. The new techniques identified in the document should prove invaluable for future programs requiring an end product as complex as that delivered under the Saturn program, as the use of these techniques will enhance product quality and reliability and decrease cost and manpower requirements. Use of the document will also allow greater management emphasis to be placed on potential problem areas.

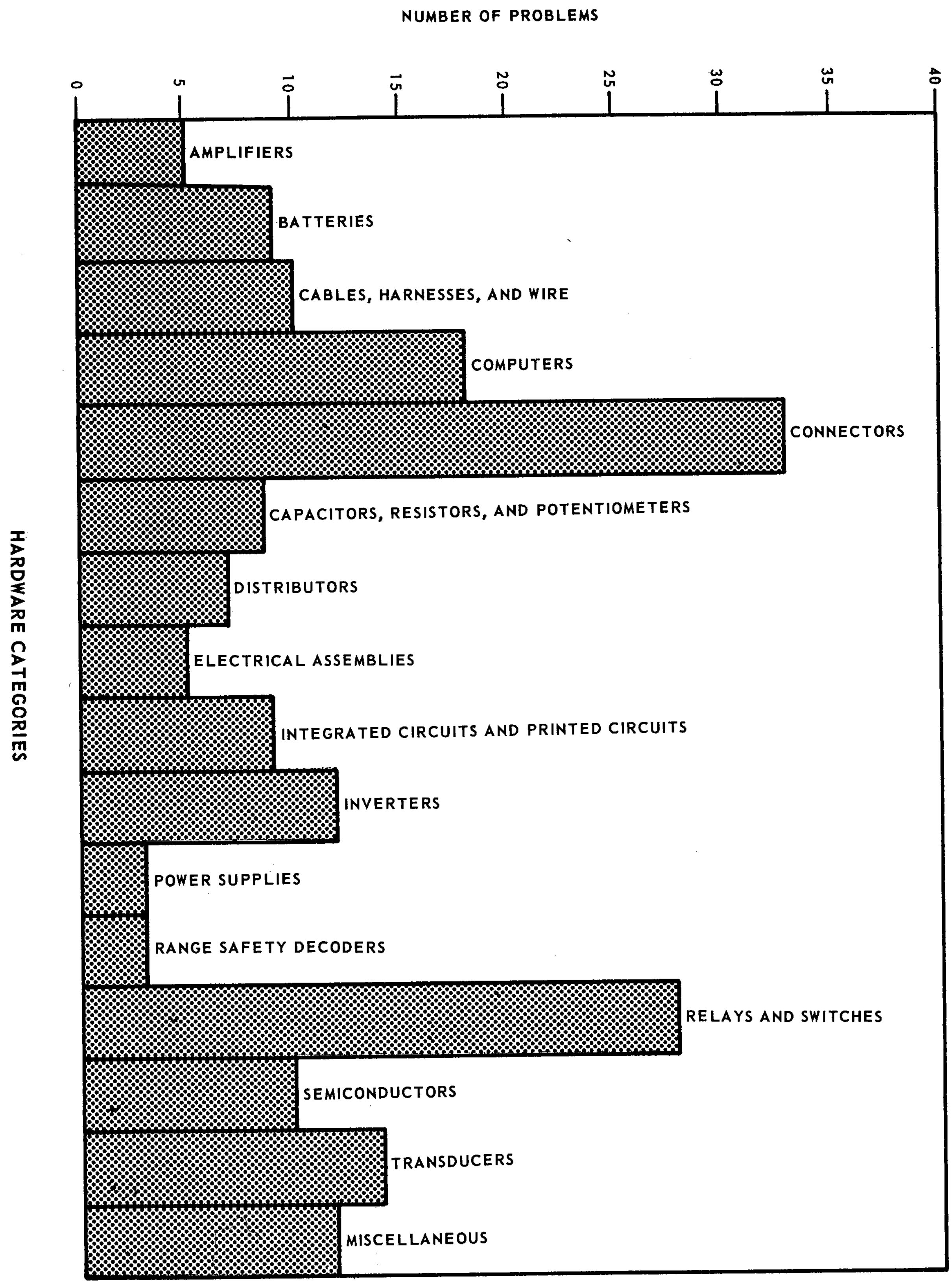
SECTION 1

ELECTRICAL

HARDWARE INDEX ELECTRICAL

HARDWARE INDEX ELECTRICAL

HARDWARE INDEX ELECTRICAL



PROBLEMS BY HARDWARE CATEGORIES (ELECTRICAL)

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PROBLEM INDEX ELECTRICAL

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Connector	51 (25)
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PROBLEM INDEX ELECTRICAL

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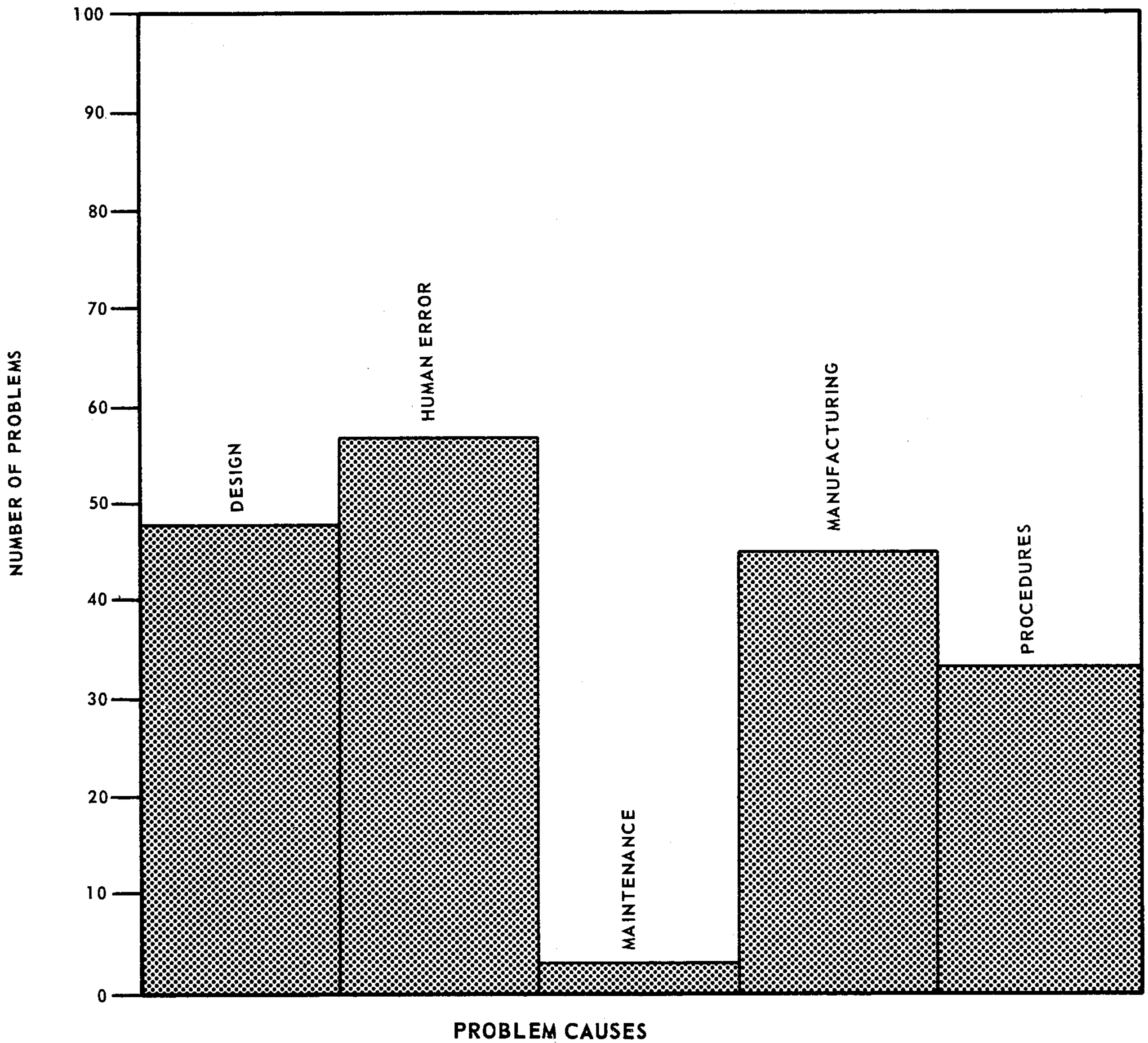

CONDITION INDEX ELECTRICAL

CONDITION INDEX ELECTRICAL

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Flight Control Computer	43 (7)
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Multiplexer	74 (8)
Pressure Transducer	71 (8)
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Printed Circuit Board Assembly	56 (5)
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Propellant Utilization Computer	45 (17)
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CONDITION INDEX ELECTRICAL

CONDITION INDEX ELECTRICAL

CONDITION INDEX ELECTRICAL

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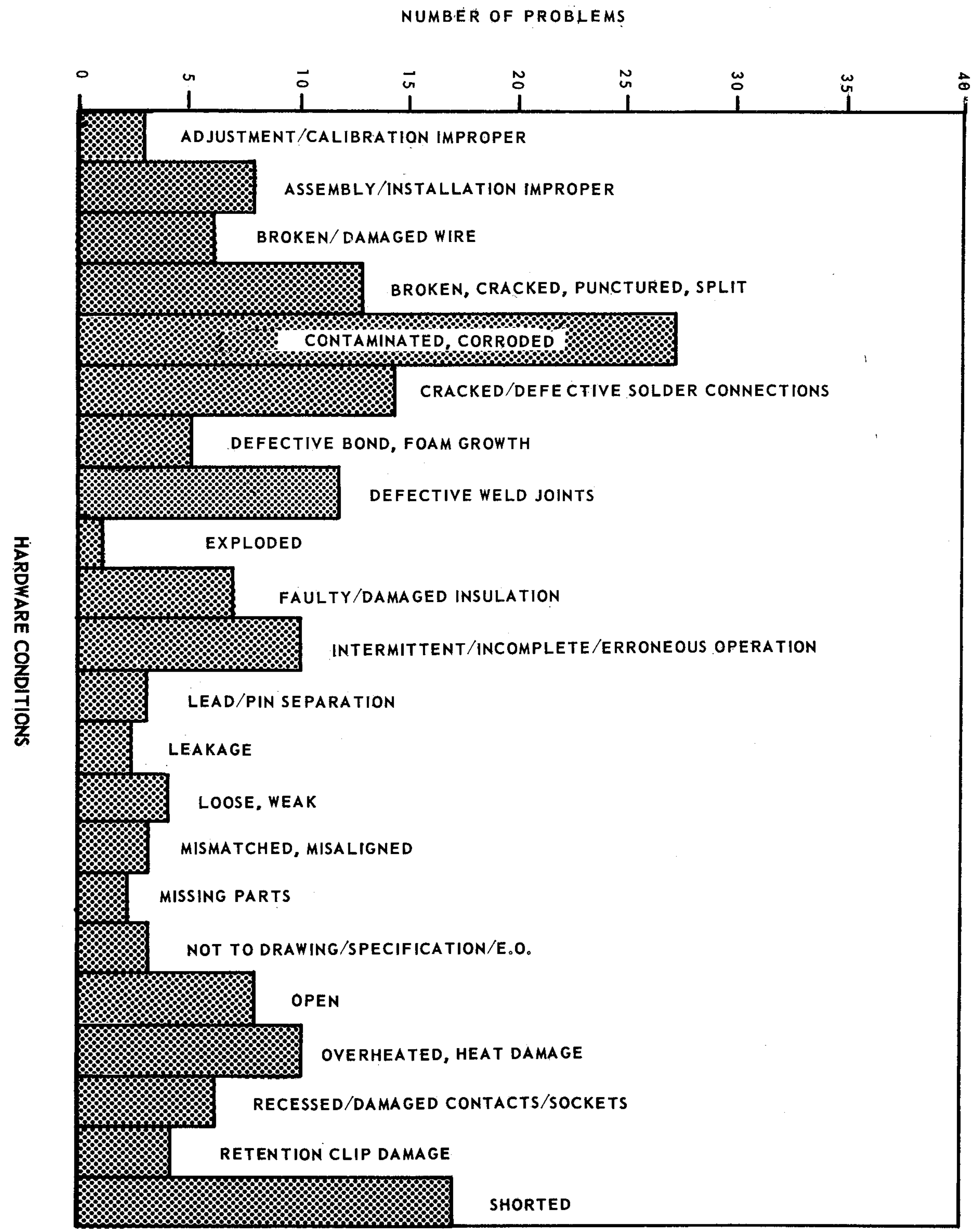
Silver-Zinc Battery	36 (9)
Static Power Inverter	59 (8)
Switch Selector	66 (20)
Temperature Transducer	72 (12)
Voltage Regulator	75 (12)



PROBLEMS BY CONDITIONS (ELECTRICAL)

ELECTRICAL PROBLEM SUMMARY

AMPLIFIERS

No	Hardware	Ref Code*	Problem	Cause	Effect	Remarks/Suggestions
1	DC Amplifier	A	Calibration point out-of-tolerance in run mode.	Change in contact resistance of the low calibration relay contacts.	Unstable operation and erroneous data.	Institute use of HI-REL components. Incorporate closer testing controls after assembly and after installation.
2	DC Amplifier	A	Hi-calibration point out-of-tolerance in run mode.	Damaged inductor in relay filter.	Unstable operation and erroneous data.	Institute use of HI-REL components. Incorporate closer testing controls after assembly and after installation.
3	DC Amplifier	A	Erratic output.	Resistance changes in relay contacts or calibration resistors.	Erroneous readings.	Institute use of HI-REL components. Implement acceptance tests that will identify defective units.
4	DC Amplifier	F	Unable to calibrate.	Loose mounting nut on the amplifier power supply transformer.	Loss of correlation of data to a calibration value.	Caution personnel to use more care during fabrication. Initiate inspection point during amplifier power transformer mounting.
5	DC Amplifier Assembly	A	Inductor resistance varies.	Damage to wire during winding of the inductor.	Actual readout values lower than predicted values.	Implement additional vendor tests for production amplifiers to ascertain proper operation prior to shipment.

*For reference code identification, refer to Introduction, pg. 2.

BATTERIES

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Nickel-Cadmium Battery	B	Voltage drop during heater actuation sequence.	Heater circuit wire lodged between battery post and strap.	Reduced voltage; short.	Ensure suppliers acceptance tests and contractors process specifications are adequate to ensure verification of the absence of shorts between terminals. Establish inspection requirements and acceptance tests that will identify defective units.
2	Nickel-Cadmium Battery	A	High resistance short.	Small particle of wire in battery.	Loss of output voltage.	Institute tighter inspection controls during battery assembly.
3	Silver-Zinc Battery	F	Thermostat cut off lower than specified.	Thermostat in wrong location.	Loss of 28 VDC power.	Revise drawings and manufacturing inspection procedures to ensure proper assembly and operation.
4	Silver-Zinc Battery	A	Cell would not accept electrolyte during activation and expelled large amounts during load tests.	Insufficient plate clearance due to improper manufacture.	Battery damage or loss.	Institute 100% vendor inspection requirements to monitor plate group thickness tolerances. Revise activation procedures to reduce possibility of electrolyte expulsion.
5	Silver-Zinc Battery	C	Heater failure.	Sustained excessive heater circuit current.	Battery explosion.	Institute use of improved battery heater control circuitry, including a thermostat in series with the heater blanket, to protect against overheating and ensure a fail-safe operation. Increase gap between cell terminals to preclude shorting cells. Eliminate excessive wiring in the battery and provide adequate insulation on battery connectors and terminals for protection from covers and encasements.

BATTERIES (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
6	Silver-Zinc Battery	B	Excessive heat following battery connection.	Cellophane separator missing from one of the positive plates.	Short; loss of voltage.	Establish mandatory inspection points during fabrication and assembly operations to ensure proper installation of cellophane separators.
7	Silver-Zinc Battery	C	Heater circuit fails to energize at low temperature.	Defective solder joint between sensor lead and temperature controller.	Loss of battery output in a cryogenic environment.	Redesign controller circuit eliminating all possible solder joints and instigate more stringent inspection during manufacturing.
8	Silver-Zinc Battery	C	Threaded metal insert becomes loose and drops on plates.	Inadequate bonding of insert to cell.	Short circuit.	Institute a bonding check, for batteries of this type, to verify that adequate bonding of insert to cell exists.
9	Silver-Zinc Battery	C	Application of two and one half times the rated VRMS during battery resistance testing.	Procedural inadequacy.	Shorted windings.	Ensure specifications and procedures are correct and within the tolerance range of the components being tested.

CABLES, HARNESSES, AND WIRE

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Cable	E	Intermittent open.	Polyurethane material on connector pins.	Loss of continuity.	Initiate adequate vendor connector process controls by developing black light inspection techniques to screen for polyurethane contamination. Develop cleaning procedure for pins.
2	Cable Assembly	A	Intermittent connector contact.	Contamination from adhesive used during fabrication, and deterioration of a connector seal.	Intermittent signals and loss of data.	Establish requirements for scheduled connector change out. Revise manufacturing specifications and procedures to preclude contamination problems. Institute 100% inspection during fabrication.
3	Cable Assembly	A	Shorted connector.	Improper assembly during manufacture.	Erroneous output signals.	Caution assembly personnel to use proper cable fabrication methods. Ensure personnel are properly trained and certified. Institute tighter inspection requirements and functional checks after fabrication.
4	Cable Assembly	B	Frayed outer jacket; crushed insulation.	Personnel traffic.	Electric arc to stage structure; opens and shorts.	Route cables to preclude personnel traffic damage. Institute use of special ladders for workmen and provide protective coverings where possible.
5	Crosslinked, Polyalkene Insulated, Electric Copper Wire	F	Base metal deposit on conductor.	Inclusion of foreign material between the wire strands during fabrication.	Poor solderability.	Implement adequate manufacturing process and inspection controls to eliminate deficiency.

CABLES, HARNESSES, AND WIRE (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
6	Electrical Wire	F	Teflon and FEP jacket contamination.	Inadequate vendor process controls.	Change in insulation resistance.	Perform a 100% wet dielectric and/or spark test at receiving inspection. Perform visual inspection for foreign material and/or surface irregularities.
7	Electrical Wire	B	Insulation indentations, and fibrous materials embedded in fiberglass and adhering to jacket.	Inadequate quality requirements for procurement of wires.	Insulation breakdown; short.	Establish requirements for laboratory inspection and test for all bulk-type procurement in addition to normal inspection.
8	Harness Assembly	B	Outer insulation damaged and shield exposed.	Unsatisfactory standard repair procedure.	Erroneous propellant utilization system mass indications.	Rework ana repair of harness assemblies should be dispositioned by a Material Review Board rather than standard repair procedures.
9	Propellant Utilization Cable Assembly	C	Corrosion.	Poor workmanship resulting in loss of seal and entrapment of moisture.	Fails resistance tests.	Ensure personnel are trained and certified for work in cable and wire harness fabrication and assembly. Institute 100% inspection during fabrication, assembly, and installation of cable and wire harness assemblies.

CABLES, HARNESSES, AND WIRE (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
10	Wire Harness	C	Numerous defects such as split sealing grommets, improperly crimped sockets, and broken insulation cups.	Poor workmanship and inspection in production.	Failure to function properly.	Ensure personnel are trained and certified for work in cable and wire harness fabrication and assembly. Institute 100% inspection during fabrication, assembly, and installation of cable and wire harness assemblies.

CAPACITORS, RESISTORS, AND POTENTIOMETERS

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Ceramic Capacitor	F	Lead separated from body of capacitor.	Inadequate lead bonding.	Inoperative capacitor.	Implement tighter manufacturing controls and improve lead bonding process to eliminate deficiencies.
2	Fixed Carbon Resistor	F	Parameter deviations.	Improper manufacturing capping process.	Out-of-tolerance values.	Change manufacturing process to include proper capping procedures. Initiate inspection controls both during manufacturing and receiving.
3	Potentiometer	C	Fails resistance tests.	Defective tap welds resulting in open windings.	Improper output.	Institute thermal shock screening tests for detection of defective welds and provide redundant nickel silver tap welds.
4	Potentiometer	F	Shorted.	Internal metallic chip contamination.	Erratic control of external circuits.	Implement closer inspecting during manufacturing and receiving.
5	Tantalum Foil Electrolytic Capacitor	F	Excessive DC leakage between insulated terminals and case.	Improperly cured insulating material.	Inoperative capacitor.	Change drawings to specify a preferred capacitor style employing tantalum-to-glass hermetic seals.
6	Temperature Sensitive Resistor	F	Intermittent opens during temperature cycling.	Poor lead welds, cracked transfer tabs, and cracked silicon resistive element.	Failure of part.	Implement tighter manufacturing inspection and revise process controls during lubrication. Institute screening procedure to include aging at rated power and temperature.

CAPACITORS, RESISTORS, AND POTENTIOMETERS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
7	Variable Air Trimmer Capacitor	F	Short circuits.	Metal particles internal to the capacitor.	Inoperative capacitor.	Caution vendor personnel of cleanliness procedures during fabrication. During receiving inspection, select random samples for X-ray testing.
8	Variable Wirewound Resistor	F	Improper rotation of shaft.	Design deficiency.	Loss of wiping action.	Ensure through proper testing that item design is satisfactory.
9	Wirewound Resistor	F	Large fallout of precoat material.	Insufficient lead support by external molding.	Part cracking; open circuit.	Change drawings to provide for proper lead support. Provide 100% receiving inspection to screen out any defective items.

COMPUTERS

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Flight Control Computer	E	Premature mode excitation during power-off and issuance of first motion command.	Design error.	Premature initiation of stage function.	Implement a drawing change to install a blocking diode in the computer circuitry.
2	Flight Control Computer	E	Defective relay.	Internal contamination.	Inhibition of relay operation.	Initiate vendor manufacturing and testing improvements during and subsequent to relay assembly.
3	Flight Control Computer	E	Defective relay driver.	Intermittent open in transistor.	Erratic computer input.	Institute tighter transistor screening tests during receiving inspection.
4	Flight Control Computer	E	Printed circuit board in contact with filter casting.	Improper design.	Short in the spacecraft control mode select circuit.	Redesign the affected P. C. boards for proper mechanical location.
5	Flight Control Computer	E	Noise on the power bus.	Other equipment on the same power bus.	Noise on the servo-amplifier outputs.	Ensure compatibility of equipment sharing the same power source.
6	Flight Control Computer	E	Defective magnetic amplifier.	Inadequate rework operations resulting in an unsoldered connection.	Delayed outputs.	Caution personnel to ensure that all connections in reworked areas have been made. Initiate inspection checks during assembly.

COMPUTERS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
7	Flight Control Computer	E	Capacitor open in the phi-dot yaw filter.	Defective solder connection (lot oriented) at the capacitive element to lead connection.	Improper frequency response.	Implement 100% visual inspection after capacitor soldering. Use stress relief soldering methods and subject lot samples to pull test.
8	Launch Vehicle Digital Computer	E	Defective memory module.	Faulty thermal compression bond in a transistor flatpack.	Power-on sequencing can not be accomplished.	Institute tighter screening techniques on stocked and subsequently manufactured items.
9	Propellant Utilization Computer	C	Transistor failure.	Inadequate heat sinking.	Improper output.	Implement higher torquing values to provide more efficient heat transfer from transistors to heat sinks.
10	Propellant Utilization Computer	B	Degraded inverter voltage.	A reversed capacitor in the AC voltage regulator.	Loss of P.U. valve control.	Ensure that personnel are trained and certified for P.U. computer manufacture. Institute additional inspection points as required. Subject assembled voltage regulators to a 2 1/2 hour "burn-in" time to detect reversed installation of components.
11	Propellant Utilization Computer	B	Low feedback voltage on P.U. valve position potentiometer.	Shorted capacitor in the valve modulator.	Erroneous output from the P.U. computer.	Institute use of HI-REL components. Require a 150 hour "burn-in" time to be logged on all computers prior to acceptance testing and an additional 50 hour "burn-in" time after replacement of any computer module.

COMPUTERS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
12	Propellant Utilization Computer	B	Low voltage output from the fixed phase inverter.	Marginal circuit design; failure of power transistors due to a combination of worst case tolerances and circuit parameter conditions.	Loss of P.U. valve control.	Ensure that component tolerances and circuit parameters are compatible. Devise screening tests to detect and eliminate marginal conditions.
13	Propellant Utilization Computer	B	No P.U. valve amplifier output.	Transistor output below requirement due to a high resistance weld on the transistor lead.	Loss of mass measurement signals.	Institute 100% weld inspection with the aid of magnification. Ensure personnel are trained and certified for work on welded electronic module assemblies.
14	Propellant Utilization Computer	B	Open circuit.	A faulty shield connection at coaxial connector.	Coarse mass LOX indicator remains at full position.	Ensure that process specifications impose a torque requirement for coaxial cable connections.
15	Propellant Utilization Computer	B	Defective LH_2 summing potentiometer.	Welding pressures breaking down the winding insulation to the mandrel.	Short circuit.	Incorporate redundant tap leads, improved tap material, improved manufacturing procedures, and additional inspection points during manufacturing operation. Subject completed potentiometers to thermal cycling prior to installation to ensure that defective units will not be installed as flight worthy hardware.

COMPUTERS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
16	Propellant Utilization Computer	C	Loose trim pot allowing 360° rotation.	Improper torque applied.	Erroneous output readings.	Ensure procedures clearly define torquing requirements. Ensure adequate tools are available and personnel should be trained in torquing techniques.
17	Propellant Utilization Computer	C	Defective valve modulator.	Discrepant capacitor and broken weld at a diode lead.	Erratic operation of valve positioner.	Institute use of HI-REL components and the latest welding and soldering techniques.
18	Propellant Utilization Computer	C	Compensating resistor out-of-tolerance.	Puncture of Mylar tape during assembly of a P. U. oven component, allowing a tuning wire to contact the thermal insulation at the point of puncture.	Low output at null setting.	Perform tighter inspection to preclude tape punctures during assembly. Select proper Mylar tape thickness to reduce the susceptibility of assembly damage.

CONNECTORS

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Coaxial Cable Connector	A	Connector separated from cable.	Insufficient assembly methods.	Loss of continuity.	Implement vendor procedures for proper mating of connector to cable and monitor through 100% inspection.
2	Coaxial Connector	B	Inner conductor extends past connector surface.	Flexing of cables after cables were taped together.	Failure in the direct wire RF check.	Maintain proper coaxial cable length and ensure cables are not taped or bonded together in any way prior to or during installation.
3	Connector	E	Defective female socket.	Top half of spring clip missing.	Intermittent pin contact.	Revise inspection procedures to include 100% visual inspection during assembly.
4	Connector	C	Wires separated from back of solder cups.	Poor enforcement of soldering requirements.	Discontinuities.	Implement better enforcement of solder requirements and inspection of all solder cups prior to installation of wires.
5	Connector	C	Mislocated wires; crossed and mismatched connectors.	Inadequate controls for mating and demating electrical connectors.	Critical commands being sent to wrong components.	Conduct a continuity check of wire bundles by personnel other than those attaching individual wires to the various connector pins. Institute extensive use of reference designators, clocked connectors, tamper proof seals, and wire bundle clamping. Avoid use of identical connectors in close proximity.

CONNECTORS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
6	Connector	F	Bent rear contact leaves; cracks in area of pin retention leaf crimp.	Insufficient crimp operation and improper rear-to-front leaf offset.	Inoperative connector.	Implement 100% inspection controls during and subsequent to manufacture. Ensure that personnel are trained and certified for work on connectors.
7	Connector	F	Damaged cavity retention device.	Insertion bullet shank lengths not to specification.	Improper socket retention in the connector; loss of continuity.	Ensure manufacturing controls specify correct insertion tool. Initiate vendor personnel training on proper assembly methods. Color code insertion bullets.
8	Connector	B	Recessed socket contacts.	Misalignment caused by connector backshell grommet twisting and skewing the contacts.	Loss of continuity.	Institute use of a dry powder lubricant during assembly and provide grommet torsional relief by backing off the connector backshell.
9	Connector	B	Recessed contacts.	Incorrect positioning of contacts during initial installation.	Loss of continuity.	Ensure personnel are trained and certified for work on connectors. Institute X-ray inspection after connector assembly.
10	Connector	B	Recessed and damaged contacts.	Workmanship; handling error.	Loss of continuity.	Ensure personnel are trained and certified for work on connectors. Institute X-ray inspection after connector assembly.

CONNECTORS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
11	Connector	B	Recessed sockets.	Insufficient lead slack in harness bends at connectors resulting in excessive axial loads on the connector contacts.	Loss of continuity.	Band all large gauge connector leads (size 0 and 4) at their point of entry into connector to provide an external visual inspection for contact recession.
12	Connector	B	Coupling springs weak.	Lack of heat treatment on coupling springs.	Unsatisfactory locking action; loss of continuity.	Ensure that supplier routing procedures require that heat treatment be performed immediately prior to plating process.
13	Connector	B	No spring load on coupling nut.	Excessive mating and unmating cycles.	Loss of continuity.	Establish time and cycle replacement requirements for connectors prone to numerous mate and demate activities.
14	Connector	B	Snapring displaced from locking groove.	Technician error which resulted in marginal snapring engagement.	Grommet movement; mating problems.	Ensure that personnel are trained and certified for work on connectors. Snapring should be designed such to preclude marginal engagement.
15	Connector	B	Insufficient strength in retention cavity to hold contacts in place.	Technician error during assembly or rework operations.	Loss of continuity.	Ensure that personnel are trained and certified for work on connectors.

CONNECTORS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
16	Connector	B	Retention clip will not hold pin contact.	Clip tine bend dimensions less than drawing requirements.	Loss of continuity.	Institute 100% inspection on retaining clip tines prior to insulator bonding.
17	Connector	B	Defective bonding between retaining disc and grommet.	Contamination introduced during the manufacturing process.	Low insulation resistance; grommet extrusion.	Develop a holding fixture to minimize connector handling during priming and bonding operations. Instruct personnel to wear Nylon gloves for connector handling during manufacturing and rework operations.
18	Connector	B	Recessed pins.	External force exerted on the connector cable (sharp bend radius near the connector mounting) plus the normal force imposed during the mating operation.	Open circuit.	Institute use of connectors that will not be degraded under forces sustained during normal mating operations. Ensure that cable routing is such that external forces and sharp bends near the connector do not exist. Implement X-ray inspections after connector installation or rework has been accomplished.
19	Connector	B	Bent and recessed pins.	Misalignment due to grommet twisting.	Loss of continuity.	Institute use of a dry powder lubricant during assembly operations and provide grommet torsional relief by backing off the connector backshell.

CONNECTORS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
20	Connector	B	Recessed pins.	Retention disc installed backward into the connector.	Loss of continuity.	Institute 100% inspection on all connectors and ensure that tooling is such that it will not allow the retention disc to be installed backwards.
21	Connector	B	Cracked silicone rubber inserts.	Thermal shock encountered during cryogenic conditions.	Insulation breakdown; short circuit.	Replace all cryogenic connectors having silicone rubber inserts with connectors that contain Teflon inserts.
22	Connector	B	Damaged retention clips.	Lack of detailed instructions and rework procedures.	Loss of continuity; electrical short.	Issue directives requiring that detailed rework instructions and caution notes be included in modification instructions for rework operations. Implement additional inspection points as required.
23	Connector	B	Broken retention clip.	Workmanship.	Loss of continuity.	Ensure that personnel are trained and certified for work on connectors.
24	Connector	B	Socket cavity damaged during rework operation.	Insertion bullets incorrectly dimensioned by supplier.	Loss of continuity.	Ensure that supplier engineering drawings correctly define dimensions of insertion bullets. Color code insertion bullets for positive identification.

CONNECTORS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
25	Connector	B	Insert rotation in connector shell.	Insert debonding from shell due to application of excessive torque.	Loss of continuity.	Ensure personnel are trained and certified for work on connectors. Ensure that manufacturing and assembly procedures clearly specify torque requirements for connectors.
26	Connector	B	Corrosion on outer surface and between coupling ring and connector barrel.	Moisture under connector insulation.	Loss of structural integrity; possible short.	Moisture penetration can be prevented by establishing new methods to provide an internal barrier to moisture laden air (anti-wicking plug) and an external barrier (tape wrapping) to prevent insulation foam intrusion into cable conductors and connector coupling hardware.
27	Connector	B	Continuous drifting of the propellant utilization system indications.	Welding in process on the stage which introduced noise into the P.U. system.	Erroneous LOX level readings.	Ensure that no welding operations are in process during checkout operations.
28	Cryogenic Connector	C	Glass insert cracks at cryogenic temperatures.	State-of-the-art problem; also inadequate test and inspection.	Possible leakage.	Tighten inspection criteria. Conduct leak check, electrical insulation test, and visual magnification inspection.
29	Miniature Connector	B	Missing leaf spring and low pin retention forces.	Inadequate inspection by suppliers.	Electrical opens or intermittents resulting in loss of critical circuit functions.	Impose more stringent inspection requirements and criteria on suppliers of critical electrical connectors.

CONNECTORS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
30	Quick Disconnect Connector	F	Electrical discontinuity and high millivolt drop.	Marginal pin retention and connector mating incompatibility.	Connector discontinuities.	Provide 100% inspection on connectors for conformance to specification requirements with emphasis on pin size, retention and continuity, and resistance checks.
31	Replaceable Contact Connector (Crimp Type)	C	Pin recession.	Inadequate inspection after assembly.	Low pin retention force. Opens or intermittents resulting in loss of critical circuit functions.	Provide 100% verification of contact retention force after assembly of every replaceable pin connector.
32	RF Coaxial Cable Connector	B	Torque relaxation of jam nut.	"Set" occurring after initial torquing.	Intermittent shield connection. Complete separation of cable from connector.	After initial torque, retorque after a minimum of 24 hours. Apply torque paint after final torque.
33	Right Angle Coaxial Connector	F	Punctured Teflon dielectric.	Misalignment of wire to connector.	High signal loss or open circuit of cable/connector.	Institute use of straight connectors. Incorporate X-ray testing during receiving inspection to verify proper alignment.

DISTRIBUTORS

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Auxiliary Power Distributor	E	Shorted distributor diode.	Inductive spikes due to a design change in the GN_2 solenoid valve.	Reset water coolant valve control relay.	Implement test subsequent to rework to check out feasibility of design change prior to in-service use.
2	Electrical Distributor	A	Foam growth increasing in physical dimension.	Incorrect curing process.	Loss of electrical function due to stress.	Ensure that temperatures and length of time for adequate curing are maintained.
3	Sequence and Control Distributor	A	Corroded distributor relay tie bar, nicked relay base, missing cover gasket, and nicked wire bundle.	Improper fabrication and rework techniques; contamination introduced during preventive maintenance checks.	Potential component malfunctions.	Caution personnel on the effects of contamination and ensure environment is suitable for fabrication and assembly operations. Institute tighter inspection requirements and controls.
4	Timer/ Propulsion Distributor	A	Solder contamination from magnet brackets found in relays.	Relay overheating during base mount brazing processes, causing magnet bracket solder to flow.	Intermittent relay operation.	Ensure that manufacturing procedures clearly specify that relays be moved through brazing unit rapidly to prevent prolonged heat exposure. Institute 100% inspection on all completed assemblies.
5	Thrust OK Distributor	A	Burned-out resistors.	Defective breakout box in the special test setup for electromagnetic compatibility testing.	Loss of capability to detect an "engine out".	Ensure testing procedures and equipment are compatible with distributor circuitry.

DISTRIBUTORS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
6	Thrust OK Distributor	A	Inconsistent time delays.	Voltage transients caused by relay bounce.	Premature SCR firing.	Revise circuitry to compensate for relay spiking. Institute an effective testing program.
7	Thrust OK Distributor	A	No voltage output.	Wiring error in distributor.	Loss of thrust OK signals; premature engine cutoff.	Add additional check points to distributor checkout program to catch wiring discrepancies. Institute 100% vendor inspection during assembly.

ELECTRICAL ASSEMBLIES

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Electrical Assemblies	D	Defective safety wiring.	Inadequate tools and facilities.	Short.	Establish a special area for installing safety wire, and ensure the use of proper tools designed specifically for safety wiring.
2	Electrical Control Assembly (ECA)	D	Leaky spark exciter connector seal.	Inadequate connector seal design.	Improper spark rate; failure to deenergize no. 1 spark plug on command.	Incorporate a design change to hermetically seal connector to spark exciter canister.
3	Electrical Control Assembly (ECA)	D	Damaged transistor.	Inadequate test procedure.	False ignition detect signal.	Ensure that test procedures are sufficient to properly check out assemblies to preclude damaging components.
4	Electrical Control Assembly (ECA)	D	Weak solder joint.	Inadequate inspection of "blind" solder joints.	False engine cutoff command.	Initiate directive to eliminate all "blind" solder joints from assemblies. Provide 100% inspection for solder joints.
5	Electronic Control Package	D	Shorted transistor.	Improper sealing during manufacturing; off-the-shelf component.	Spark deenergized timer ceases to operate.	Specify use of HI-REL components to preclude obtaining off-the-shelf items.

INTEGRATED CIRCUITS AND PRINTED CIRCUITS

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Cerpaks	F	Lead contamination.	Handling and assembly processing.	Possible failure.	Caution personnel on the proper handling of items. Initiate 100% assembly inspection points.
2	Integrated Circuit	F	Degraded operation.	Open metallization at the oxide step caused by inadequate deposition of aluminum over the corner of the step.	Improper amplifier output.	Screen devices by thermal cycling tests. Study manufacturing process to determine the conditions leading to metallization problem. Institute tighter vendor inspection controls.
3	Printed Circuit Board	E	Voids in solder attaching the top hat welds.	Improper clearance; incorrect welding tip used to weld top hat to component lead prior to soldering.	Integrity of joint damaged.	Ensure that top hat to circuit land clearance is within specification. Also, ensure use of the proper type welding tip.
4	Printed Circuit Board	A	Timer count-down distributor stays in "reset" position.	Reversed installation of polarized capacitor.	Improper output.	Specify closer vendor quality inspection during assembly.
5	Printed Circuit Board Assembly	F	Solder cracking.	Unsatisfactory assembly and soldering techniques.	P. C. board failure.	Ensure board assembly is accomplished by personnel trained in proper soldering techniques. Inspect 100% during fabrication.

INTEGRATED CIRCUITS AND PRINTED CIRCUITS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
6	Printed Circuit Card	A	Open circuit in resistor.	Broken glass substrate.	Improper voltage output from circuit.	Redesign resistor to include a larger glass substrate. Identify redesigned items by a white ring around the body.
7	Printed Circuit Card	A	Open solder joints.	Improper soldering techniques.	Constant output signal with no input.	Institute 100% quality inspection during manufacturing. Ensure personnel are properly trained and certified for soldering work.
8	Printed Circuit Card	A	Open circuit in gate transformer.	Imperfections in wire used to wind transformer.	Out-of-tolerance condition in multiplexer for related channel/frame.	Institute 100% vendor inspection during fabrication and assembly of transformer. Establish acceptance requirements for wire purchase.
9	Transistor Flatpack	F	Foreign particles and hanging leads.	Insufficient controls by vendor during manufacture.	Intermittent failures.	Institute operator certification and specify 100% inspection. Tighten manufacturing process controls and screening tests.

INVERTERS

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Chilldown Inverter	C	Excessive current surge.	Three-phase oscillator transformer output windings retaining charges causing out of sync windings.	No output.	Provide a DC current reset for cores in three-phase oscillators for assurance that the windings will always be in sync when inverter is turned on, and to eliminate voltage spikes.
2	Chilldown Inverter	C	Open circuit in three driver modules.	Arcing current from a partially mated connector.	No output.	Ensure that personnel are trained and certified for connector handling and assembly. Institute 100% inspection on all connectors after final assembly to ensure proper installation.
3	Chilldown Inverter	C	Shorted driver transistors.	Metallic contamination introduced during fabrication of the heat sink/transistor assembly.	Burned out driver transformer and module driver.	Caution personnel on the effects of contamination and ensure environment is suitable for fabrication and assembly operations. Institute a resistance check between driver transistor and case on completed assemblies. Add protective coatings to critical components and institute tighter inspection requirements and controls.
4	Chilldown Inverter	C	Zener diode failure in heat sink assembly.	Overheating during manufacturing.	Failure of associated components; improper output	Institute use of HI-REL diodes and conduct tests on the diodes, prior to assembly, that will ensure proper operation after assembly.

INVERTERS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
5	Chilldown Inverter	C	Burned out transistors.	Shorting bar inadvertently left on test equipment.	No output.	Ensure personnel are trained and certified for use of complex test equipment. Insert "warning notes" in procedures to ensure that shorting bar is removed at the proper time.
6	Chilldown Inverter	C	Shorted tantalum electrolytic capacitors on input side of inverter.	Reverse resistance testing.	Damage to filter module; degraded inverter performance.	Ensure that test procedures clearly define that resistance testing will be conducted in the "forward" direction only.
7	Inverter Converter	C	Open transistor in voltage regulator.	Excessive voltage input.	Loss of DC output voltage.	Ensure test procedures specify voltage limits and applications. Caution personnel on hazards of over voltage inputs.
8	Static Power Inverter	B	Inverter output voltage erratic.	Short circuit between inverter case cover and the collector terminal of the voltage regulator transistor.	Erratic recirculation pump operation; low recirculation pressure.	Institute use of HI-REL stud-mounted transistors.
9	Static Power Inverter	B	Inverter output erratic.	Inverter transistor failure caused by voids in solder bond between chip and case.	Erratic recirculation pump operation; low recirculation pressure.	Institute use of HI-REL stud-mounted transistors.

INVERTERS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
10	Static Power Inverter	B	Broken solder connection.	Faulty test equipment at the supplier.	Degraded inverter output.	Ensure test equipment is adequately designed to preclude inducing failures in assemblies. Institute vibration screening tests to identify broken solder connections.
11	Static Power Inverter	B	Low output voltage.	Broken wires due to repeated disturbance of multistrand wire during inverter rework.	Loss of recirculation capability.	Ensure that rework/modification procedure sequence is such that wire disturbances are kept at a minimum. Institute additional inspection points during rework/modification operations to preclude defective inverters from being accepted as flight-worthy hardware.
12	Static Power Inverter	B	Zero inverter output.	Poor solder connection between terminal and transistor in the overcurrent protection circuit.	Loss of excitation voltage and power to the recirculation pump.	Establish 100% inspection of all solder joints by vendor, contractor, and government personnel. Consider use of welded joints rather than soldered joints.

POWER SUPPLIES

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Power Supply	E	Shorted capacitor.	Improper component positioning during assembly.	Current output with no load.	Initiate X-ray testing on completed capacitor assembly modules to verify proper positioning of components. Add caution notes to drawings to avoid future errors.
2	56 Volt Power Supply	E	High output.	Marginal design problem occurring after design change.	Possible voltage breakdown/erratic operation of external circuitry.	Ensure design changes are compatible with existing equipment parameters. Test design prior to in-service use.
3	5 Volt Excitation Module	C	Improperly wired connector cable.	Cable connector incorrectly labeled.	Loss of output voltage.	Ensure that personnel are trained and certified for the manufacturing and labeling of connectors. Institute 100% inspection in areas of connector labeling and manufacturing.

RANGE SAFETY DECODERS

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Range Safety Decoder	C	Negative transistor voltage leakage.	Silicon control rectifier leakage.	Improper output.	Institute use of HI-REL components and ensure that pretest operations will adequately identify defective components.
2	Range Safety Decoder	C	Power transistor leakage.	Contamination introduced during manufacturing process.	Unstable voltage output.	Ensure that manufacturers' contamination control requirements are adequate to preclude problem. Institute special tests (screening) prior to installation of piece parts.
3	Range Safety Decoder	B	Broken wire in potted connector	Mishandling by personnel.	Loss of continuity between connector and decoder ground.	Institute additional inspection points and add caution notes to procedures. Ensure personnel are trained and certified for work on connectors and their installation into Range Safety Decoders.

RELAYS AND SWITCHES

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Explosion Proof Switch	F	Heavy internal corrosion.	Chemical interaction of switch materials.	Internal open or short circuiting.	Verify chemical compatibility of materials prior to production of item.
2	Hydraulic Starter Switch	C	Failure to actuate.	Excessive thrust bearing friction in the motor control circuit.	Open circuit.	Institute use of nonrotational thrust bearings in the motor control circuit. Establish and institute time and cycle requirements for starter switch.
3	LOX Pressure Switch	A	Switch actuation out-of-tolerance.	Inadequately sealed solder joints.	Leakage of hermetic seal and reduction in tank ullage pressure.	Ensure personnel are trained for solder work. Institute 100% inspection during fabrication.
4	Power Transfer Switch	E	Inability to transfer power.	Low voltage due to excessive drop along the checkout cables.	Loss of external system power.	Ensure that cable lengths are considered in initial checkout station designs for voltage supply adequacy.
5	Power Transfer Switch	A	Erratic output.	Contamination introduced during rework.	Loss of power.	Caution personnel on the effects of contamination and ensure environment is suitable for fabrication and assembly operations. Institute tighter inspection requirements and controls.
6	Power Transfer Switch	A	Out-of-tolerance cam angle.	Tolerance for cam angle not established prior to manufacture of parts.	Cam could not be driven into the cam dwell region at minimum voltage.	Ensure all design parameters are considered to meet system requirements prior to production. Institute testing program for checkout prior to production.

RELAYS AND SWITCHES (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
7	Pressure Switch	C	External helium leakage.	Damage received during previous calibration checks.	Leakage; possible depletion of helium supply.	Institute post calibration test procedures to check for leakage. Plug or cap calibration port after leakage tests to prevent supply depletion in the event of subsequent leakage.
8	Pressure Switch	B	Fails to actuate over full range.	Missing and bent locking screws; incorrect procedures.	Inability to provide accurate indication.	Initiate directives to personnel to use proper instruction manual and adjustment tools.
9	Pressure Switch	C	Crossed line connections.	Improper identification of umbilical housing.	Leakage; overpressurization of pressure switches, and rupture of switch bellows.	Incorporate positive identification procedures for handling and checkout of pneumatic equipment and lines.
10	Power Transfer Switch	F	Switch internal lead shorted to ground.	Improper lead routing during manufacturing.	Inoperative switch.	Initiate vendor inspection points when routing leads during manufacturing.
11	Relay	A	Broken coil wire.	Improper coil/relay terminal connection techniques.	Inoperative relay.	Implement 100% vendor inspection requirements. Ensure personnel are properly trained and are using the correct assembly procedures.
12	Relay	A	Inoperative relay contacts.	Melting of the glass bead on actuator rod during a previous dielectric test of relay.	Loss of function.	Ensure test environment is compatible with component being tested.

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
13	Relay	E	Intermittent open wire in reset coil.	Inadequate procedures for heat shrink of tubing during manufacture.	Abnormal relay transfer.	Revise manufacturing procedures for heat shrinking operations and institute tighter inspection controls at vendor during relay assembly.
14	Relay	E	Coil lead wire separation from relay post.	Inconsistent welding process.	Failure to transfer.	Implement drawing change to call out for use of HI-REL relays which are screened to detect this type problem. Ensure that welding process is consistent and current with the state-of-the-art.
15	Relay	F	Internal contamination.	Poor manufacturing quality control during fabrication.	Relay failure.	Review manufacturers' fabrication and inspection methods. Institute training of personnel, including proper cleanliness procedures.
16	Relay	F	Contaminated contacts.	Teflon particles on relay contacts.	Relay failure.	Purchase relays without Teflon spacers for particular AC/DC applications. Specify usage limits for procurement purposes.
17	Relay	F	Broken coil wire.	Poor vendor workmanship and inadequate soldering techniques.	Inoperative relay.	Ensure that manufacturers' production and quality requirements meet acceptable standards. Ensure personnel are certified for soldering work. Institute inspection with magnification for all soldering operations.

RELAYS AND SWITCHES (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
18	Relay	F	Open circuit condition.	Internal moisture.	Failure to transfer.	Tighten manufacturer controls and procedures. Employ a low temperature screening test prior to relay usage.
19	Single Pole Double Throw (SPDT) Switch	F	Intermittent open.	Loose contact mounting point.	Erratic operation.	Implement adequate screening procedures to detect internal deficiencies. Review manufacturers' process and inspection controls for adequacy.
20	Switch Selector	C	No telemetry signal output.	Connector shorted to ground by a scrap piece of wire.	Inability to transmit signal.	Institute rigid inspection during assembly and installation of connectors. Ensure personnel are trained and certified for work on connectors.
21	Thermal Time Delay Relay	F	Resistance changes in heater element.	Poor coil wire insulation.	Erratic time delays.	Requalify relay using improved insulation method. Investigate manufacturers' quality control practices.
22	Thrust OK Pressure Switch	F	Cracked U-frame.	Stress corrosion of 17-7PH switch material.	Actuation below requirements.	Institute switch redesign incorporating use of Inconel 718 switch material.
23	Toggle Switch	F	Internal contamination, weld defects, momentary shorting, cracks, and an annealed return spring.	Inadequate manufacturing process controls.	Inoperative switch.	Ensure screening and inspection requirements will detect switch problems. Implement 100% vendor inspection for each deficiency during switch fabrication.

RELAYS AND SWITCHES (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
24	Vent and Relief Valve Switch	F	Excessive current draw.	Defective weld joint on internal switch actuating pin.	Failure of associated circuitry.	Redesign switch to employ rivet construction rather than resistance welds.
25	2 Amp Relay Module	C	Melted wire insulation next to relay can.	Application of excessive current from an unknown source.	Warped relay; open circuit.	Ensure checkout procedures are adequate to prevent excessive current applications. Thicker wire insulation will reduce possibility of complete breakdown in the event of inadvertent application of excessive current.
26	2 Amp Relay Module	C	Contacts fail to close.	Contact accidentally burned during a previous troubleshooting operation.	Failure to function properly; open circuit.	Ensure personnel are properly trained and instructed on proper troubleshooting techniques.
27	10 Amp Magnetic Latch Relay Module	C	Failure to reset.	Heat application causing vinyl wire covering to shrink causing a short circuit.	Inability to complete circuit.	Institute use of Teflon wire coverings to prevent heat damage.
28	50 Amp Relay Module	C	Intermittent/nonfunctional motor driven switch.	"Break before make" type contacts and oxidation.	Open circuit; failure to transfer power.	Institute use of "make before break" type contacts and cycle relays several times prior to intended use to help prevent oxidation.

SEMICONDUCTORS

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Diode	F	Voids and cracks in the bonding material.	Shrinkage of silver paste bonding material.	Reduced quality and reliability.	Ensure vendor develops proper design and material processes to reduce or eliminate deficiency.
2	Diode	F	Excessive reverse current.	Shunt resistance paths due to aluminum whisker over-hanging the PN junction.	Short.	Initiate tight inspection controls and utilize random X-ray inspection subsequent to manufacture.
3	NPN Transistor	F	Shorted transistors.	Internal nickel particle contamination.	No output.	Develop screening (particle detection) techniques such as X-ray, nondestructive testing, and microscope examination of random samples.
4	Rectifier	F	Silicon pellet broken loose from header.	Inadequacy of silver paste bonding material.	Reduced quality and reliability.	Investigate use of other types of bonding material. Tighten vendor quality control during assembly of rectifier and specify proper test to evaluate adequacy of bond.
5	Silicon Controlled Rectifier (SCR)	F	Devices do not meet applicable specifications.	Misrepresentation by SCR distributor.	Questionable quality and reliability.	Institute quality assurance at user facility to establish controls and to preclude use of suspect items.
6	Silicon Controlled Rectifier (SCR)	F	Excessive electrical leakage.	Contamination introduced during processing of the Mesa chip or the silicone rubber coating.	SCR will trigger with anode voltage applied.	Redesign SCR and ensure proper operation by testing its parameters under adequate test circuit conditions. Ensure that processing requirements and controls are adequate to prevent SCR contamination.

SEMICONDUCTORS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
7	Silicon Zener Diode	F	Breakage.	Improper weld and shelf storage time.	Open circuit.	Implement 100% gross and fine leak testing, 100% thermal shock testing, 100% burn-in testing, and radiographic inspection. Distribute information concerning shelf storage times of this type diode.
8	Transistor	F	Current leakage.	Excessive internal moisture.	Unstable transistor outputs.	Discontinue Mesa type construction of transistor and implement screening requirements. Initiate manufacture utilizing Planar type construction of transistor chip.
9	Transistor	F	Internal lead wire open.	Design and material limitation.	Transistor failure.	Implement new screening specifications to detect defective items prior to use. Tighten vendor inspection controls during manufacturing process.
10	Transistor	F	Internal contamination.	Inadequate manufacturing controls.	Erratic operation.	Implement tighter vendor part screening, and X-ray all units during receiving inspection. Review manufacturer welding processes.

TRANSDUCERS

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	ASI Ignition Detector	D	Probe leads crossed.	Probe tip rotation after installation.	Fails to detect engine ignition.	X-ray probes prior to installation. Add tamper proof devices to provide visual indication of tip rotation.
2	Fuel Mass Probe	C	Shorted probe.	Unauthorized use of lubrication during assembly.	Erroneous output.	Institute stringent, limited access requirements and controls for access to and usage of lubricants.
3	Fuel Mass Probe	C	Inner and outer probe elements shorted together.	Locking pin not fully inserted into inner element of probe; inadequate procedures.	Erratic output.	Provide an assembly outline to ensure proper installation of the insulator and lock pin. Institute inspection requirements and controls to verify proper assembly.
4	Fuel Mass Sensor	B	Open circuit.	Defective spot weld attaching a tab to the inner electrode.	Loss of sensor.	Incorporate the use of a rivet in addition to the spot weld to preclude separation of the tab from the inner electrode.
5	LOX Mass Probe	C	Disengagement of pin from the probe.	Insufficient slack in the lead-in wire to the point level sensor.	Improper output.	Ensure proper probe lead wire length is maintained during assembly and ensure inspection controls are adequate to preclude discrepant probes from being installed.
6	Mass Sensor	B	Numerous defects (damaged wire, split sleeves, out of round holes, etc.).	Workmanship.	Incorrect loading and measurement.	Verify proper sensor operations subsequent to assembly and installation at supplier and contractor. Ensure personnel are trained and certified for work on sensors and probes and implement additional inspection points to preclude incorrect and faulty assembly.

TRANSDUCERS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
7	Pressure Transducer	D	Corrosion and pitting.	Potassium chloride from the spark igniter caused corrosion of the transducer sensing line.	External leakage.	Implement design change to relocate the pressure sensing line and provide redundant seals to prevent leakage.
8	Pressure Transducer	A	Leakage at tubing connection and housing plates.	Cracked solder joint caused by pressure cycling.	Failure to perform prescribed function.	Add requirements for each component to undergo vibration, proof, and burst tests at the vendors.
9	Pressure Transducer	F	High output.	Open circuit due to inadequate swaging operation.	Improper output.	Tighten manufacturers' inspection controls. Review manufacturing process for adequacy in the swaging operation.
10	Pressure Transducer	D	Pin hole in weld.	Poor alignment during welding process.	Leakage.	Revise drawings to add a split Teflon seal to reinforce flange weld. Also, advise vendor to adhere to strict welding and alignment procedures.
11	RF Detector	C	Adjustment range not sufficient for proper operation.	Poor design resulting in thermal sensitivity; tested by vendor at other than operating temperatures.	Inability to accurately measure RF power in telemetry systems.	Ensure that vendor test requirements and field usage requirements are compatible to ensure proper equipment operation.

TRANSDUCERS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
12	Temperature Transducer	B	High resistance short.	Dielectric break-down during thermal shock and vibration.	Loss of output; erroneous output.	Ensure that qualification testing is conducted under environmental conditions that simulate actual use of component. Utilize HI-REL components for transducer assembly.
13	Thermocouple Gage	B	Bent pins and chipped glass seal.	Mishandling.	Leakage; loss of vacuum in cryo-genic lines.	Ensure that personnel are trained and certified for thermocouple gage installation on vacuum jacketed lines.
14	Transducer	A	Open circuit in the resistive element.	Improper wire connection during manufacture.	Output signal too high.	Revise vendor assembly procedures and institute additional inspection points to determine proper connec-tion prior to sealing.

MISCELLANEOUS

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Amplifier Pre-regulator Module	C	Diode failure in potentiometer.	Impurity between tungsten whisker and aluminum chip.	Inability to adjust potentiometer to a null of plus or minus one volt AC.	Institute use of HI-REL components during module assembly. Institute screening tests for added assurance of HI-REL components.
2	Control Rate Gyro	E	Gyro wheel turning capability impaired; failure to start.	Weld burn-through during manufacturing resulting in spin bearing lubricant destruction.	Inability of gyro to come up to speed; gyro failure.	Revise documentation to require a gyro "run-down" test subsequent to manufacturing and acceptance tests. This should be accomplished four months prior to a launch with spares tested every six months. Institute tighter inspection control points during assembly and manufacturing processes.
3	Control Signal Processer	E	Transformer secondary open.	Broken wire.	No output from transformer.	Initiate tighter transformer quality controls at vendor during assembly.
4	Control Signal Processer	E	Suspected solder ball contamination of RFI filters.	Inadequate manufacturing procedures.	Capacitor failure in the RFI filter.	Improve manufacturing filter assembly process and add X-ray inspection requirements during fabrication.
5	Electrical Brush Material	F	Poor mechanical bond between brush block and holder.	Unsatisfactory soldering procedure.	Separation of the brush block from the brush holder.	Initiate change to soldering technique for this type brush material.
6	Electrical Ground Points	C	Inadequate aldolization of grounding surfaces.	Poor grounding practices due to inadequate procedures.	Corrosion of grounding joints.	Institute periodic inspections for grounding joints and ensure proper surface aldolization through stringent inspection requirements and controls.

MISCELLANEOUS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
7	Linear Shaped Charge Assembly (LSC)	B	Striations in LSC cover material.	Inadequate control of the Teflon forming processes.	Incomplete detonation of LSC.	Formulate specific quality standards for acceptance and rejection of cover material. Ensure that "forming" processes incorporate the latest state-of-the-art techniques.
8	Multiplexer	C	Multiplexer output zero.	Cracked solder joint on the DC to DC converter board.	Intermittent operation; loss of data.	Institute use of welded joints where possible. Ensure inspection controls are adequate to detect defective joints. Initiate screening tests (thermal shock) for additional assurance of adequate welds.
9	Safety and Arming Device (Inert)	A	Device would not move to armed position.	Possible misalignment of clutch assembly and improper grounding.	System could not be armed; loss of propellant dispersion capability.	Institute tighter quality control measures at vendor.
10	Safety and Arming Device (Live)	B	Rotor shaft overtravel.	Marginal adjustment during original assembly.	Loss of propellant dispersion capability.	Develop a mechanical test set for initial alignment and adjustment of the rotor. Increase exposure time to random vibration during Production Acceptance Tests (PAT). Increase number of switchings during PAT to a minimum of 100, and provide additional instrumentation to monitor rotor position during switchings.

MISCELLANEOUS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
11	Valve Feedback Potentiometer Filter Module	B	Voltage divider does not maintain required voltage.	An unwelded joint in the module.	Loss of propellant utilization valve control.	Institute weld marking to ensure that no welds are missed and provide 100% inspection for all welds. Impose a "burn-in" time for all P.U. computer modules prior to installation and additional "burn-in" time for computers after final assembly.
12	Voltage Regulator	C	Excessive current draw.	Short in the secondary winding of output transformer.	Short; no output.	Implement additional inspection points and tests to check transformer windings prior to encapsulating the regulator.

SECTION 2

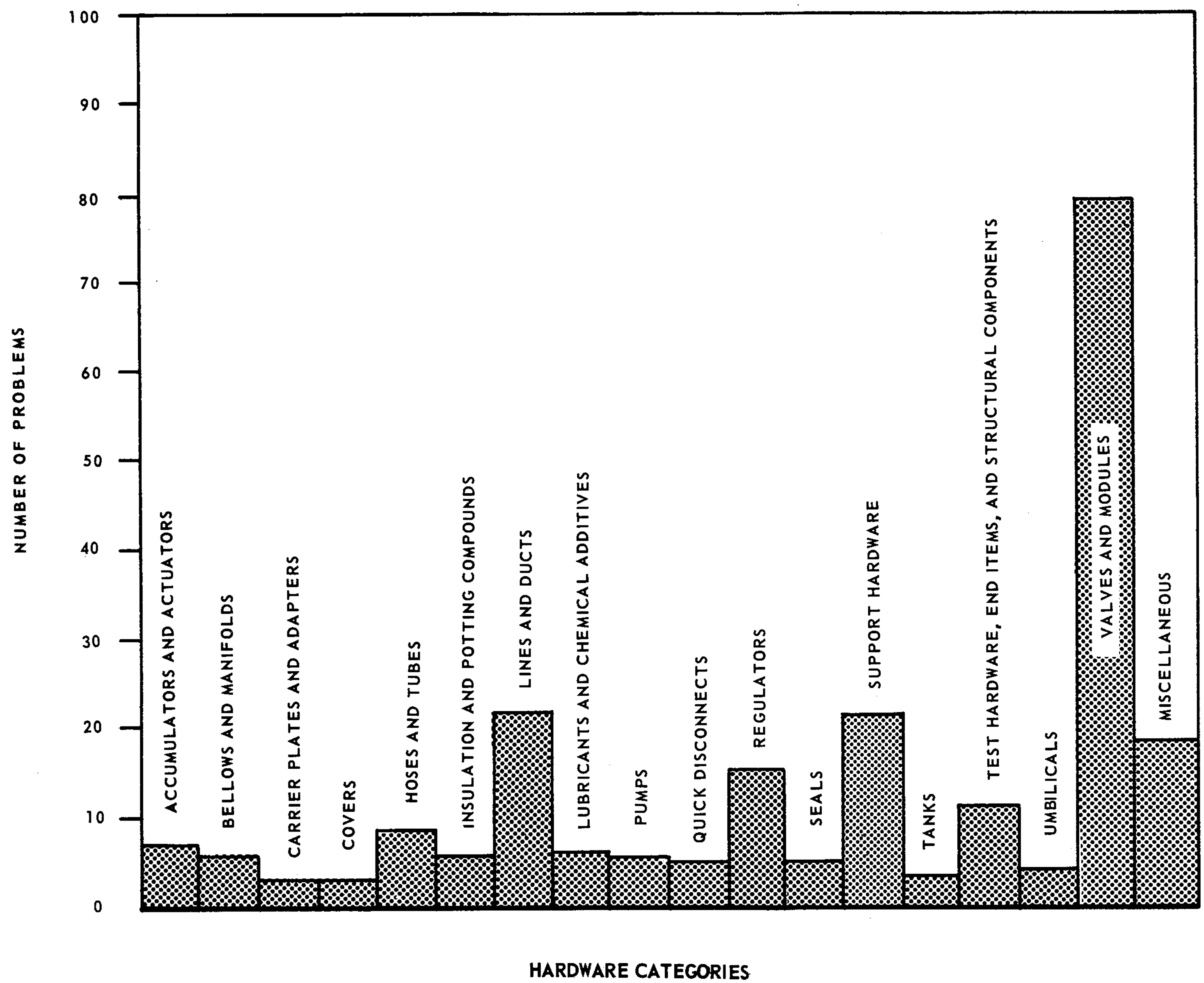
MECHANICAL

HARDWARE INDEX MECHANICAL

HARDWARE INDEX MECHANICAL

HARDWARE INDEX MECHANICAL

PROBLEMS BY HARDWARE CATEGORIES (MECHANICAL)



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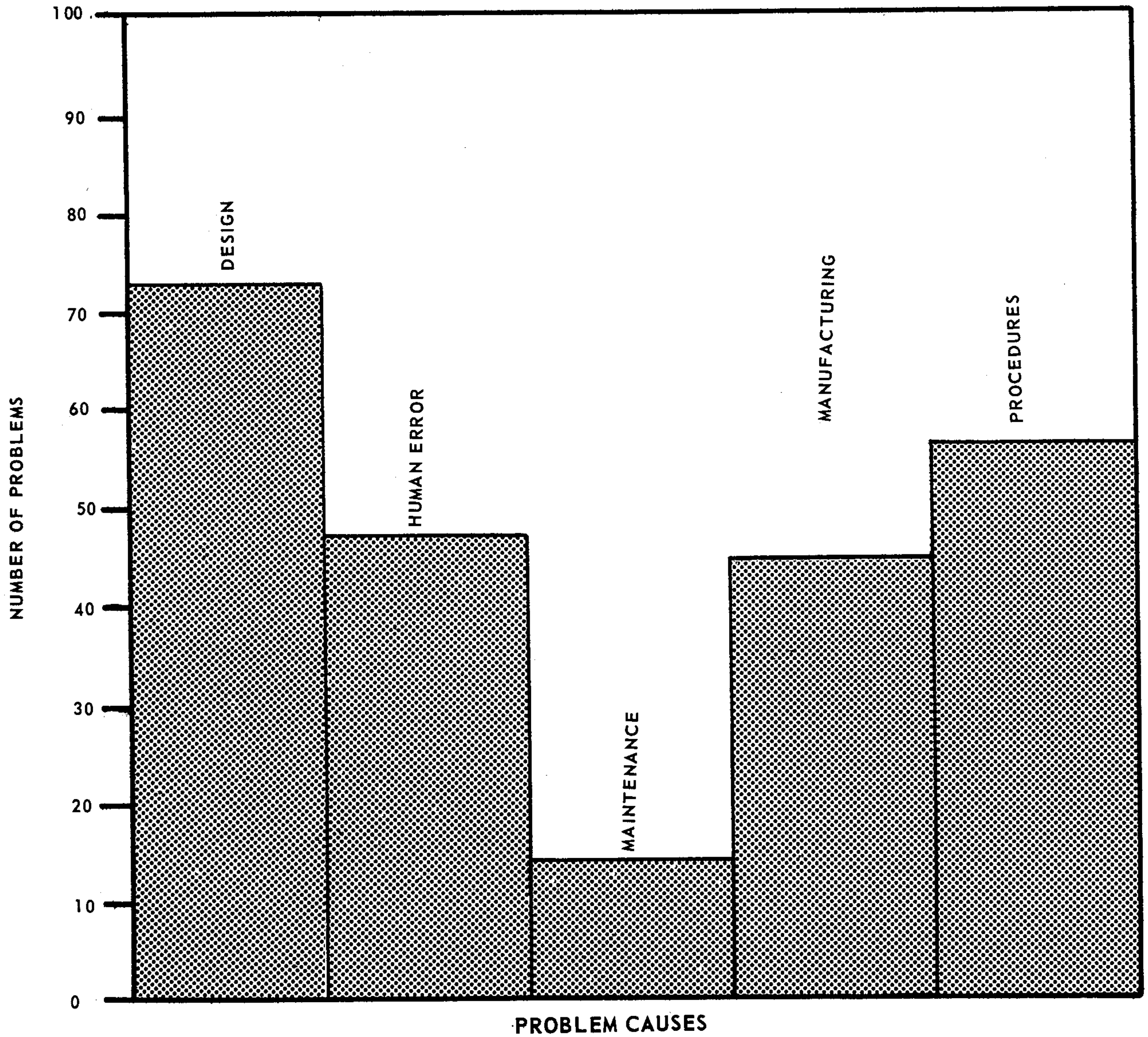

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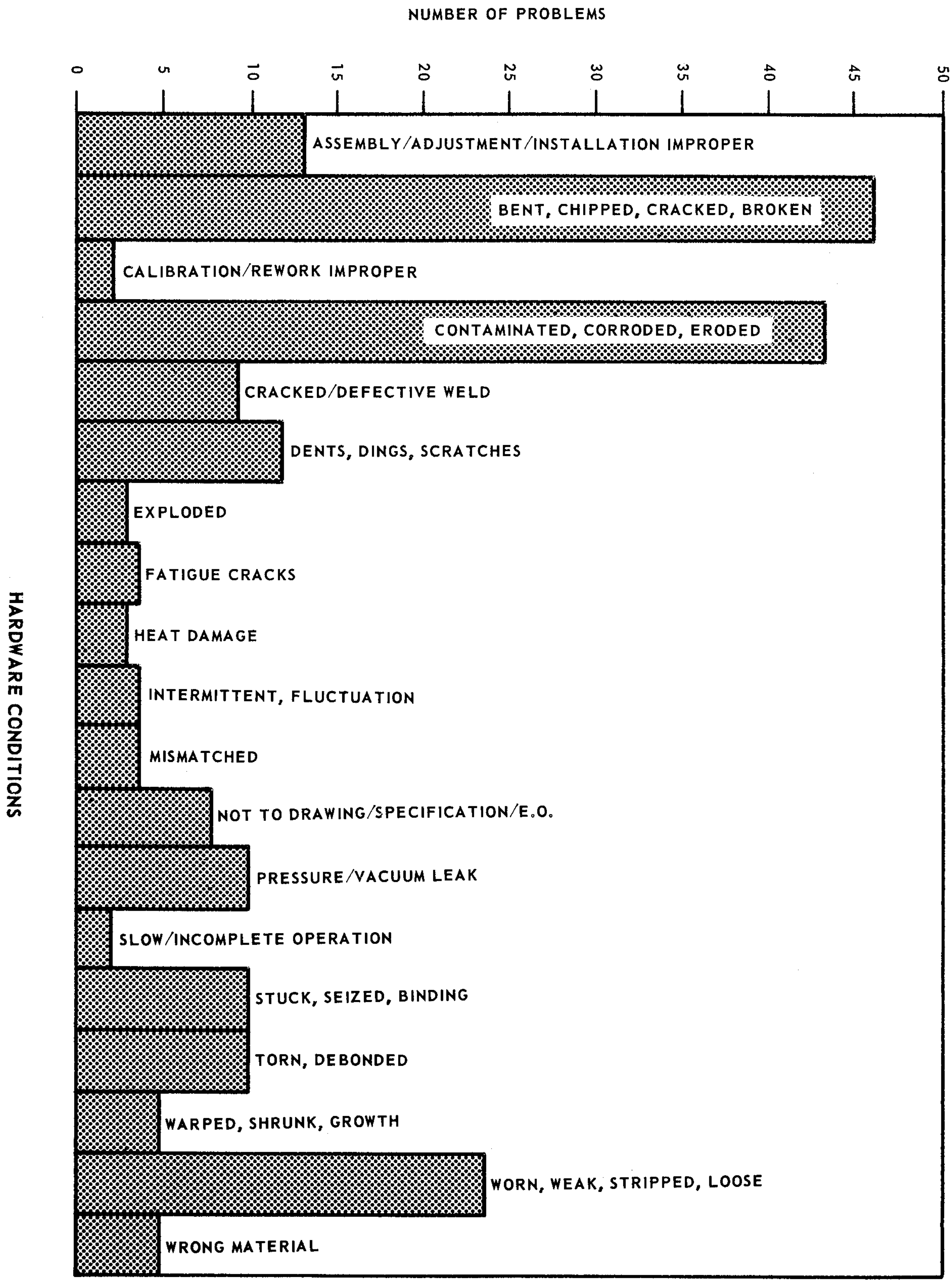

PROBLEMS BY CONDITIONS (MECHANICAL)

MECHANICAL PROBLEM SUMMARY

ACCUMULATORS AND ACTUATORS

No	Hardware	* Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	H_2O/Methanol Accumulator	E	Decreased accumulator bolt torque.	Improper flange sealing surface design and bladder relaxation.	H_2O/Methanol leakage.	Redesign the bladder and flange sealing surface. Incorporate changes into the drawings and subsequently manufactured parts.
2	Hydraulic Accumulator Reservoir	C	Gaseous nitrogen pressure decay.	Spiralling O-rings on the piston.	Loss of positive pressure in the accumulator.	Institute use of quadrangular shaped seals (QUAD-BON) instead of conventional O-rings.
3	Hydraulic Actuator	C	Excessive leakage of hydraulic fluid.	O-ring taking a slight set during storage.	Possible depletion of hydraulic fluid supply.	Cycle the actuator several times prior to checkout to restore the elasticity of the O-rings. Initiate use of quadrangular shaped seals (QUAD-BON) instead of conventional O-rings on subsequent hardware.
4	Servoactuator	A	Broken torsion spring in the actuator feedback mechanism.	Intergranular corrosion due to improper cleaning methods prior to heat treating.	Servoactuator fails to return to the zero null position.	Institute 100% inspection immediately prior to and immediately following heat treating process to ensure the absence of contamination prior to continuing the manufacturing process.
5	Servoactuator	A	Rust on piston rod.	Inadequate protection from moisture.	Seal damage and leakage.	Impose strict requirements to prevent contamination and provide for environmental protection of actuators.

*For reference code identification, refer to Introduction, pg. 2.

ACCUMULATORS AND ACTUATORS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
6	Servoactuator	A	Insufficient sealing capability of O-ring seal on pre-filtration by-pass valve.	Inadequate design resulting in the use of an under-sized O-ring.	Leakage through valve; fire hazard.	Incorporate the use of a larger cross section O-ring and provide a Teflon backup ring to prevent leakage.
7	Servoactuator	A	Out-of-tolerance stroke.	Improper adjustment for specific application.	Servoactuator position output does not correspond to input signal.	Implement step-by-step procedures for adjustment, institute training for personnel, and maintain an entry log of actuator length adjustment for its specific application.

BELLOWS AND MANIFOLDS

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	ASI Manifold	D	Excessive vibration loading.	Poor design resulting in a large, suspended mass.	Cracked welds.	Redesign manifold, replacing manifold block with tubing to eliminate the large suspended mass.
2	Hydraulic Manifold Assembly (4-way)	D	Metallic contamination lodged in 4-way control valve.	Inadequate cleaning of hydraulic manifold assembly.	Start solenoid on 4-way control valve fails to operate.	Revise cleaning specifications to a more stringent level. Ensure all sharp edges and burrs are removed after machining. Provide inspection during cleaning process.
3	Recirculation Return Manifold	B	Loss of vacuum.	Undersized threads on thermocouple due to "off the shelf" procurement.	Excessive boiloff.	Ensure that procurement of spare thermocouple gages are from the supplier of the manifold and not "off the shelf" procurement.
4	Recirculation Return Manifold	B	Bent pin in thermocouple gage.	Mishandling.	Loss of vacuum.	Institute use of protective coverings on thermocouple gages. Ensure personnel are trained and certified for work on vacuum jacketed lines.
5	Torsional Bellows	B	Corrosion.	Inadequate cleaning, drying, and lubrication specifications.	Leakage.	Impose stringent cleaning and drying processes. Utilize a corrosion resistant lubricant as a coating for torsional bellows (Ecolube 642).
6	Vent Line Bellows	B	Contaminated layer on surface of bellows material.	Material annealed in ovens in which proper atmospheric conditions were not maintained.	Cracks in bellows; scrapped material.	Conduct micrographic examination for contamination of bellows material upon receipt.

CARRIER PLATES AND ADAPTERS

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Anti-Friction Plate	A	Anti-friction holddown arm broken.	Uneven load distribution and excessive hardness of metal.	Possibility of loose parts falling into engine.	Change drawings to callout for different hardness specifications and new bonding material.
2	Carrier Plate Assembly	B	Copper seal used on aluminum tube assembly.	Nonavailability of aluminum seal at time of assembly.	Aluminum/copper incompatibility resulting in corrosion.	Specify on drawings the type seal material compatible with the tubing used. Institute inspection to comply with specification.
3	Orifice Adapter Assembly	C	Lockwire interference with static seal.	Lockwire holes drilled improperly.	Leakage.	Ensure manufacturing specifications clearly define the locations for drilling operations. For existing applications, the replacement of the seal with an O-ring should preclude leakage.

COVERS

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Purge Cover	B	Cut in material along the zipper.	Cover too small.	Inability to hold purge pressure.	Modify purge cover to allow for shrinkage.
2	Purge Cover	B	Water inside purge cover.	Condensation of air trapped inside cover.	Explosive atmosphere if purge function was lost during LH_2 filling operations.	Implement procedures to require draining of the cover prior to LH_2 purge and fill operations.
3	Shipping and Protective Materials	A	Shipping and protective materials mistaken for flight hardware.	Poor human engineering.	Ranges from test delays to possible loss of stage.	Utilize materials which either will not permit installation of the protected item or will be highly visible after installation.

HOSES AND TUBES

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Augmented Spark Igniter Fuel Injector Hose Assembly	F	Flex hose breakage.	Resonant flow-induced vibrations.	Hose failure and subsequent leakage.	Implement proper test environment conditions to assure adequacy of part operation.
2	Flex Hose Assembly	C	Hydraulic fluid leakage at the B-nut joints.	Scored flare.	Depletion of hydraulic fluid supply.	Institute additional inspection points prior to final assembly. Ensure personnel are properly trained and certified for work in hydraulic systems installation.
3	Flex Hose Assemblies	B	Difficulty in meeting specified requirements.	Vendor welding specifications not compatible with the current state-of-the-art.	High rate of rejection.	Strict adherence to MSFC welding specifications should be maintained, however, utilize vendor welding specifications if proven to be superior.
4	Fuel Return Line Hose	F	Teflon cracks.	Overaged material.	Hose failure and fuel leaks.	Purge stock of overaged Teflon hose. Inspect in use items and replace as necessary. Initiate periodic inspection of this type hose.
5	Hose Assembly	B	Leakage.	Personnel damage due to hose routing and twisting during installation.	Fire hazard.	Redesign hose assembly to provide wrench flats to prevent twisting during installation. Route hose assembly to preclude damage due to work traffic. Institute use of protective coverings for hose assemblies.

HOSES AND TUBES (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
6	Hydraulic Line (Tube Assembly)	C	Worn seals and flares.	Inadequate handling procedures; workmanship.	Hydraulic fluid leakage.	Establish and enforce adequate handling and installation procedures. Ensure personnel are trained and certified for work on hydraulic systems installations.
7	Pressure Transducer Sensing Lines (Tube Assembly)	B	System pressurization with transducer sensing lines disconnected.	Lack of redundancy.	Explosion due to over pressurization.	Install redundant set of pressure transducers with mandatory requirements that both sets be operational prior to pressurizing.
8	Tube Assembly	B	Cracked sleeve (303 stainless steel).	Sulfur in the sleeves causing the formation of a brittle non-metallic compound in the form of slivers and spheres.	Leakage.	Replace 303 stainless steel sleeves with 304 stainless steel sleeves.
9	Tube Assembly	C	Radial scratches in flared surface.	Rotation of tube assembly during installation.	Leakage.	Ensure personnel are trained and certified for work on pneumatic systems installations. Utilize proper tools to ensure that tube will not rotate during torquing operations.

INSULATION AND POTTING COMPOUNDS

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	FEP Teflon Wire Insulation	F	Shrinkage of insulation.	Variations in manufacturers' process control.	Shorts due to exposed wire.	Review existing specifications, incorporate shrinkage tests, and ensure that adequate manufacturer material controls exist.
2	LH_2 Tank Insulation	B	Loss of helium purge capability.	Torn honeycomb insulation.	Increased insulation heat transfer and LH_2 boiloff.	Utilize a spray foam type insulation which does not require a helium purge. Require insulation technicians to be certified after attending a 20-hour course in insulation bonding techniques. Refresher courses should be scheduled every 12 months.
3	LH_2 Tank Sidewall Insulation	B	Debonding of insulation.	Scorched adhesive and a previously burned area which had been improperly repaired.	Helium purge pressure drop; increased heat transfer and excessive boiloff.	Establish a training program and ensure personnel are certified on insulation bonding and repair techniques. Delete use of honeycomb insulation and use a spray foam type insulation which does not require a helium purge.
4	Tank Insulation Tile and Simulators	C	Tensile test failure at cryogenic temperature.	Test specimen process controls different from production process controls.	Loss of insulation effectiveness.	Require simulators to be processed using the same controls as production items.

INSULATION AND POTTING COMPOUNDS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
5	Spray Foam Insulation	B	Gouges to bulkhead during milling and trimming operations.	Use of inadequate milling and trimming tools.	Rework and/or scrapping of panels/sections.	Avoid use of metallic tools for trimming or milling of foam insulation. Institute personnel training.
6	Stafoam; Foam Potting Material	A	Growth of foam potting material.	Instability of foam due to its sensitivity to moisture and temperature.	Interference with electrical and mechanical component operation.	Ensure proper heat curing process is accomplished by vendor. Institute adequate inspection monitoring points.

LINES AND DUCTS

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Duct Assembly	B	Loose rivets.	Human error; use of wrong rivets.	Leakage.	Ensure drawings clearly specify the correct rivets to be used. Implement additional inspection points to ensure installations are according to drawings.
2	Fuel Feed Duct	C	Loss of vacuum.	Fatigue cracks on inner bellows assembly.	Excessive heat transfer; excessive boiloff.	Fatigue cracks can be prevented by adding an inner liner to the duct to absorb the effect of fast flowing cryogens.
3	Fuel Pressure Duct	A	Vendor proof pressure test conducted at too high a pressure.	Contractor failed to notify vendor of revised proof pressure requirements.	Possible rupture of duct.	Ensure vendor is notified of all revisions to proof pressure requirements and implement inspection points to ensure vendor testing is conducted to the latest drawing revision.
4	LH_2 Feedline	B	Incomplete weld penetration.	Poor workmanship and improper weld X-ray interpretation.	Cracked welds; line rupture.	Institute usage of the latest welding equipment and techniques. Utilize magnification for review and examination of weld X-rays. Initiate a separate 100% revaluation of all weld X-rays.
5	LH_2 Feedline	B	Longitudinal weld cracks in the inner bellows.	Improper manufacturing processes.	Loss of vacuum; structural failure.	Anneal and roll bend bellows material during forming to reduce stress and cut bellows material such that only one longitudinal weld is required.

LINES AND DUCTS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
6	LH_2 Feedline	B	Cracked glass insert in thermocouple gage.	Improper handling.	Loss of vacuum.	Ensure personnel are properly trained for thermocouple gage installation. Institute use of protective coverings for gage.
7	LH_2 Recirculation By-Pass Line	B	Loss of vacuum.	Improper installation of thermocouple gage.	Excessive boiloff.	Ensure that installation procedures provide detailed maintenance instructions for replaceable parts on vacuum jacketed lines. Ensure personnel are trained and certified for work on vacuum jacketed lines. Ensure post installation/rework tests are adequate to identify a faulty installation.
8	LH_2 Recirculation Duct	C	Loss of vacuum.	Roll seam leakage due to handling damage.	Excessive heat transfer; excessive boiloff.	Ensure personnel are trained and certified and institute use of protective coverings.
9	LH_2 Recirculation Line	B	Outgassing of contamination.	Contamination from the aluminum rupture disc.	Loss of vacuum.	Utilize corrosion resistant steel (CRES) rupture discs in cryogenic recirculation lines.
10	LH_2 Recirculation Line	B	Outgassing of contamination; loss of vacuum.	Contamination introduced during replacement of thermocouple gage.	Excessive boiloff.	Ensure that procedures provide detailed maintenance instructions for replaceable parts on vacuum jacketed lines. Ensure personnel are trained and certified for work on vacuum jacketed lines.

LINES AND DUCTS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
11	LH_2 Recirculation Return Line	B	Loss of vacuum.	Cracked glass bead seal in thermocouple gage.	Excessive boiloff.	Institute use of protective coverings on thermocouple gages. Ensure personnel are trained and certified for work on vacuum jacketed lines.
12	LH_2 Recirculation Return Line	B	Outgassing of contamination.	Improper cleaning and purging.	Loss of vacuum.	Ensure that cleaning and purging procedures reflect adequate controls to prevent the inclusion of contamination. Lines suspected of outgassing due to contamination should be pumped down for longer periods of time than normal requirements.
13	LH_2 Vent Line	B	Loss of vacuum.	Insufficient torque on thermocouple gage.	Excessive boiloff.	Increase thermocouple gage torque from 60 inch pounds to 90 inch pounds maximum.
14	LOX Auxiliary Pressurization System Line Assembly	B	High frequency fatigue.	Excessive pressure levels applied by the LOX auxiliary pressurization system.	LOX leakage; fire hazard.	Change line orifice size to limit the pressure applied to the stage pressurization system.
15	LOX Feedline	B	Loss of vacuum.	Defective circumferential bellows to outer duct welds.	Excessive heat transfer; excessive boiloff.	Change manufacturing procedures to include a mass spectrometer leakage check under elevated temperatures.

LINES AND DUCTS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
16	LOX Feedline	B	Loss of vacuum.	Improper vacuum pumping procedures.	Excessive LOX boiloff.	Ensure that procedures clearly define proper pumping procedures and techniques, including when to begin pumping operations and the frequency of pumping operations.
17	LOX Fill and Drain Line	B	Cracked mount weld; line flattened at adjacent bend.	Mishandling and work traffic.	Line leakage; fire hazard.	Institute use of protective coverings for lines susceptible to damage from work traffic.
18	LOX Fill and Drain Line	B	Fracture of line bellows.	Metal fatigue caused by high frequency cycling.	Leakage; fire hazard; possible line collapse.	Strengthen line by adding lines within the bellows sections and replace the single ply bellows with a three ply bellows.
19	LOX Vent Line Assembly	B	Weld deficiencies.	Poor workmanship and inadequate inspection.	Leakage; fire hazard; possible line collapse.	Incorporate a one piece vent line to eliminate multiple welds. Ensure welders are trained and certified. Improve inspection through use of magnification of weld X-rays.
20	Stainless Steel Ducting	C	Corrosion of welds.	Inadequate fabrication, cleaning, and packaging procedures.	Leakage.	Avoid use of carbon steel wire brushes during fabrication and ensure passivation of weld areas. Maintain cleanliness during cleaning and packaging operations.

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
21	Turbopump Fuel Duct	D	Cracks in weld joints.	Inadequate inspection planning and control of process flow.	Leakage.	Ensure vendor inspection requirements clearly define inspection operations.
22	Vacuum Jacketed Feedline	B	Shrinkage of the Kel-F seal on the evacuation valve.	Seal material inadequate for application.	Loss of vacuum.	Institute use of an all metal spring seal in place of the Kel-F seal.

LUBRICANTS AND CHEMICAL ADDITIVES

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Electroplating Copper Additives	F	Debonding of solder to copper laminate.	Additives (organics) in the copper plating solution.	Electrical separation between solder and copper pad.	Implement change in copper plating process to eliminate bright acid copper additives in the solution.
2	Epoxy/ Trichloroethylene	F	Loosening of epoxy.	Epoxy incompatible with trichloroethylene.	Debonding of epoxide items.	Initiate and disseminate information to prevent using trichloroethylene with epoxies.
3	Lubricant	F	Variation in sensitivity to contact with LOX.	Lubricant incompatibility.	Possible loss of lubrication and accelerated wear out rate.	Ascertain usage environment and conduct compatibility tests. Tighten inspection controls at vendor and establish formula guidelines in order to produce lubricant with consistent chemical qualities.
4	Lubricating Agents	D	Use of inadequate, excessive, or wrong type lubricant.	Inadequate lubrication procedures.	System contamination.	Maintain tight controls on availability and accessibility of lubricants. Ensure proper application through personnel training.
5	Reproduction Machine Toner	F	Associated hardware contamination.	Toner transferred by hand from drawing to hardware.	Possible hazard condition in LOX environment.	Ensure that controls exist to preclude toner contamination.
6	Transparent Chemical Film (Alodine 1500)	C	Confusion in determining film thickness, uniformity, and presence.	Transparency of films.	Inadequate protection of metallic surfaces.	Use colored films where permissible.

PUMPS

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Auxiliary Hydraulic Pump	C	Pump output below specification.	Broken compensator spring guide.	Output out of tolerance; low pressure.	Increase spring guide material strength and dimensions.
2	Auxiliary Hydraulic Pump	C	Pump output below specification.	Improper adjustment of the pressure compensator.	Out of tolerance output; low pressure.	Implement step-by-step procedures for adjusting and locking pump compensator.
3	LH_2 Recirculation Pump	B	Bearing failure.	Dry spinning of pumps during leak checks.	Failure of the pumps to adequately perform propellant recirculation.	Utilize bearings which are either self lubricating or do not require lubrication during dry spinning operations.
4	LOX Turbopump	D	Crack in first stage turbine wheel.	Cracks caused by poor design.	Possible engine explosion due to turbine breakup.	Initiate a redesign of turbopump and verify proper operation by testing under operational parameters.
5	Turbopump	D	Broken O-ring.	Wrong installation sequence used.	Fuel leakage at fuel balance cavity supply line adapter.	Revise modification manual to include proper installation sequence and warnings to use extreme care during installation.
6	Turbopump	D	Gross contamination.	Use of loose pump flange cover as a seal during transit.	Possible turbopump and engine damage.	Caution personnel to use more care when installing covers and seals, and institute tighter inspection controls. Redesign covers to afford adequate protection during shipping operations.

QUICK DISCONNECTS

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Fluid Quick Disconnect	C	Mismatched connector halves.	Deterioration of ground half due to repetitive use.	Excessive Q.D. leakage.	Implement a preventive maintenance program to replace continuously used items at periodic intervals.
2	LH_2 Disconnect	B	Excessive gap between the ground and vehicle fill disconnect halves.	Improper adjustment during installation; human error.	Leakage with potential fire hazard.	Develop tighter quality control surveillance during installation.
3	LOX Disconnect Assembly	B	Sheared bolts.	Poor visibility resulting in improper positioning of GSE half of disconnect during mating.	LOX leakage; fire hazard.	Modify attaching latch bars to provide better visibility when mating GSE and airborne disconnect assemblies.
4	Quick Disconnect	B	Scratch on sealing surface of Q.D. bellows probe.	Scratched during manufacture and was approved for use "as is".	Leakage of Q.D. with potential fire hazard.	Initiate a manufacturing change to require the use of a Teflon protective cover during handling operation.
5	Quick Disconnect Assembly	A	O-rings in the Q.D. take a permanent set.	O-ring lubrication washed away by H_2O/Methanol media.	Quick disconnect leakage.	Initiate a preventive maintenance schedule for periodic O-ring change-out. Revise Q.D. specifications for the use of a more compatible O-ring material on subsequent quick disconnect assemblies.

REGULATORS

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Dome Loaded Pressure Regulator	B	Internal leakage.	Inadequate design; poppet and guide slightly galled from contamination.	Overpressurization.	Redesign regulator for new guide and spring and eliminate external sensing ports. Install filters to prevent contamination.
2	Dome Loaded Pressure Regulator	A	Seat leakage.	Erosion marks and metal particles due to contamination.	Out-of-tolerance operation.	Initiate a preventive maintenance program and provide for seat replacement at regular intervals.
3	Dome Loaded Pressure Regulator	F	Internal leakage.	Torn diaphragm.	Loss of pressure regulation.	Redesign diaphragm using materials that are less susceptible to tearing.
4	Dome Loaded Pressure Regulator	C	Fails to maintain a set pressure.	Normal in-service wear-out.	Leakage; out of tolerance operation.	Establish a preventive maintenance program requiring replacement of time sensitive parts on a regularly scheduled basis.
5	Dome Loaded Pressure Regulator	A	Seat damaged.	Heat generated in stopping flow of gas.	Leakage; improper regulation.	Redesign regulator seat to be more compatible and reliable under operating conditions.
6	Dome Loaded Pressure Regulator	B	Pressure creep.	Seat damaged during assembly.	Inability to maintain a stable pressure.	Implement tighter inspection controls during regulator assembly.
7	LOX Bubbling Regulator	A	Leakage.	Fractured spring due to alloy flaw.	Out-of-tolerance operation.	Institute 100% inspection during and subsequent to spring manufacture.

REGULATORS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
8	LOX Dome Purge Regulator	A	Erratic relief poppet operation.	Main inlet and relief poppets bent due to improper regulator adjustment.	Fails to open; improper regulation.	Caution operating personnel not to adjust the regulator without inlet pressure applied.
9	Nitrogen Flow Regulator	A	Diaphragm leakage.	Consistent cycling due to low flow regulation resulting in diaphragm rupture.	Out-of-tolerance operation.	Redesign regulator to contain a rubber-backed diaphragm backer plate to prevent rupture. Install a parallel regulator to prevent continuous cycling at low flow.
10	Pressure Regulator	A	Contaminated poppet assembly.	Contamination from leak detector soap solution.	Excessive regulator output pressure.	Revise test procedures to require leak check by submerging the regulator in deionized water with subsequent vacuum drying.
11	Pressure Regulator	E	Leakage.	Improper installation techniques and tests.	Poor regulation.	Initiate personnel training in proper installation methods. Require leak and pressure tests for regulators prior to installation.
12	Pressure Regulator	B	Chattering and pressure creep.	In-service wear.	Inability to maintain a stable pressure.	Institute a preventive maintenance program to provide that parts subjected to wear be replaced at regular intervals.
13	Pressure Regulator	B	Pressure creeping.	Bent poppet stem causing galling of stem in guide; human error.	Overpressurization.	Incorporate tighter manufacturing inspection controls during assembly. Ensure that post assembly functional tests will identify faulty hardware.

REGULATORS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
14	Pressure Regulator	B	Leakage past seat.	Seat deterioration.	Inability to maintain a stable pressure.	Incorporate design changes to install a glass impregnated teflon seat which is less susceptible to deterioration.
15	Pressure Regulator	B	Erratic regulation.	Inadequate design for application.	Inability to maintain a stable pressure.	Research design thoroughly and ensure that qualification test program will provide a suitable product.

SEALS

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Conoseal	C	Scratched seal.	Workmanship and handling.	Leakage at connection.	Provide for adequate seal protection and caution personnel in the handling and installation of delicate parts.
2	Cryogenic Seal	B	Leakage.	Unfavorable tolerance buildup.	Fire hazard.	Redesign seal to allow for unfavorable tolerance buildup.
3	Hydraulic Accumulator and Large Piston Seals	C	O-ring spiralling.	Inadequate design.	Leakage.	Use quadrangular shaped seals (QUAD-BON) instead of conventional O-rings.
4	Naflex Seal Installation	A	Leakage.	Handling and workmanship.	System degradation.	Special handling and polishing requirements, in addition to strict adherence to fit-up procedures and torque values, should preclude leakage problems.
5	Seal	A	Gouged seal.	Improper installation.	Fluid leakage.	Incorporate procedural changes and personnel training to preclude installation errors.

SUPPORT HARDWARE

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Aluminum Alloy Coupling Nut	F	Cracked nuts.	Manufacturer deviation from temper specification.	Stress corrosion failure; leakage.	Ensure existence of proper vendor processing controls and inspect 100% for correct hardness of alloy.
2	Aluminum Raw Stock	B	Cracking of material during forming operations.	Inadequate research into forming methods compatible with the physical properties of the material.	Cost and schedule impact.	Thorough studies and analyses should be conducted on test articles prior to procuring large quantities of new material and starting manufacturing of production hardware.
3	Bracket	B	Corrosion.	Chemical finish inadequate for environment.	Structural degradation.	Institute use of corrosion resistant paint.
4	Clamps (In-Tank)	B	Loose, unfastened and/or damaged clamps.	Poor workmanship.	Provide a source of material for injection into turbopumps.	Issue bulletins as a remainder of the need for extreme caution and attention to detail when performing in-tank operations.
5	Coupling Nut	E	Improper temper of B-nut.	Manufacturer deviation from specification.	Stress corrosion.	Tighten vendor quality control to ensure proper alloy hardness. Initiate eddy current tests at receiving inspection to verify proper B-nut temper.
6	Flange Bolt	F	Sheared Bolt.	Corrosive environment and stress corrosion.	Structural degradation.	Ensure bolt selection is resistant to a corrosive environment. Select bolt size and strength to eliminate effects of stress corrosion.

SUPPORT HARDWARE (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
7	Flared Tube Fitting Sleeve	F	Cracked sleeves.	Sulfur additive to stainless steel material.	Tube leakage.	Initiate drawing change to use different class sleeves. Verify change by torque check prior to each cryogenic tanking. Use sulfur additive sleeves only in noncritical applications.
8	Flared Tube Installation	A	Leakage.	Inadequate flaring, fit-up, and torquing procedures.	System degradation.	Strict adherence to flaring procedures, fit-up procedures, and torque values should preclude leakage problems.
9	Flared Tube Plugs	B	Dislocated O-rings.	Marginal plug design and subsequent over torquing of plug.	Leakage past O-rings.	Train assembly personnel in torquing procedures. Call-out for an inspection point during O-ring installation.
10	Flexloc Nut	F	Loose nut.	Retaining bolt too short.	Improper holding action.	Change drawing to specify longer bolt. Initiate inspection control of this specific problem.
11	High Carbon Steel Bolts	A	Hydrogen embrittlement.	Improper heat treating and processing.	Bolt fracture.	Institute rigid requirements for heat treating and subsequent processing of bolts.
12	MF Tube Fittings with Ratchet and Spring Locking Devices	A	Washer spring failure.	Inadequate procurement requirements.	Leakage.	Replace spring with lockwire on existing fittings. Establish new requirements for future procurement, or establish Class I drawings for this requirement after procurement.

SUPPORT HARDWARE (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
13	Mounting Inserts Anchored in Honeycomb Material	B	Bonding breaking loose when electrical components are mounted.	Bonding insert in cavity with potting compound not providing sufficient strength.	Loss of electrical functions.	Future specifications should include a requirement for metallic filler to be added to potting compound and use of X-ray inspection methods should be instituted.
14	Self-Locking Nut	F	Cracked nuts.	Improper vendor alloy process.	Loss of bolt holding action.	Ensure manufacturer inspection process and controls are adequate to screen defective items.
15	Self-Locking Nut	B	Unattached bolt, washer, and nut found in tank.	An uncrimped nut (crimping is required to ensure a self-locking action).	Unattached hardware can migrate into LOX and LH_2 pumps.	Issue bulletins and set up displays in shop areas to emphasize the importance of the proper installation of lock fasteners. Institute 100% inspection of all baffle installation attaching hardware after all in-tank operations.
16	Socket Head Cap Screw	F	Sheared screw.	Excessive depth of pilot hole; human error.	Loss of screw holding capability.	Establish tighter quality inspection controls during manufacturing process. Check receiving inspection procedures for adequacy in determining properties of socket head cap screws.
17	Socket Head Screw	F	Cracked heads and rounding of the internal wrenching flats.	Inadequate manufacture and heat treating.	Failure of bolting action and/or misapplication of correct torque values.	Inspect and perform hardness tests on existing stock. Purchase screws directly from conforming manufacturers.

SUPPORT HARDWARE (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
18	Support Bracket	B	Cracked welds on gas distributor brackets.	Excessive heat build-up during start and stop portions of weld.	Structural failure.	Institute additional inspection points with the aid of magnification and change welding requirements to have support weld ends chamfered to remove possible cracks.
19	Titanium Metals used in LOX Systems	F	Explosive reaction of titanium in contact with oxygen.	High sensitivity to impact in LOX environment.	Loss of titanium containers and damage to surrounding structure.	Titanium is not recommended for construction of LOX tanks for space vehicles.
20	Weld Sleeve	D	Foreign material trapped in weld.	Inadequate cleaning.	Pin hole leak.	Change drawings to include additional cleaning requirements and fabrication restrictions.
21	Welded Support Hardware (Ladders)	B	Defective welds. Lack of fusion in welds.	Proof load requirements not maintained.	Weld separation; equipment damage.	Establish requirements for periodic proof load tests. Perform X-ray inspection on all welds.

TANKS

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	APS Bladder Expulsion Tank	C	Sustained differential pressure.	Test personnel error combined with GSE valve leakage.	Bladder rupture.	Provide check points to ensure that fill valves are open prior to system venting. Instruct personnel on proper venting operations.
2	Bulkhead Assembly	B	Indentations in aft LOX foil seal.	Faulty workmanship.	LOX leakage.	Machine counterbore surfaces to a closer tolerance and replace aluminum foil seals with lead coated seals.
3	Cylinder Assembly	B	Corrosion.	Inadequate manufacturing controls resulting in the use of a defective adhesive primer.	Degradation of structural integrity.	Initiate use of a new primer, Koropom 515-70, under spray and pour foam insulations.
4	Fuel Tank	A	Hi-Lock rivet found in fuel tank.	Hi-Lock rivet failure due to stress corrosion resulting from improper manufacture.	Contamination; structural failure with tank damage.	Implement more stringent quality control measures at the rivet vendor and contractor facilities.
5	Helium Storage Tanks	C	Incorrect weld wire.	Inadequate controls on acquisition, storage, and use of weld wire. Inadequate inspection after weld.	Weak seams caused by embrittled weld structure.	Maintain tighter controls on weld procedures and manufacturing processes. Also, institute eddy current tests at receiving inspection.

TANKS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
6	LH_2 Tank	B	Cracks in stringers.	Improper machining of stringer ends; improper handling techniques; and, misalignment between stringers and cylinders.	Structural collapse.	Polish stringer ends and edges, and replace Hi-Shear impact driven rivets with Hi-Lock fasteners. Specify the maximum allowable misalignment between stringers of adjacent cylinders and incorporate changes to tooling and handling fixtures.
7	LH_2 Tank Quarter Panel	B	Hard spots.	Inadequate techniques used in forming operations.	Cracks in the panels.	Use thoroughly tested and developed material characteristics and forming techniques.
8	Oxidizer Tank Assembly	A	Contamination of tank.	Improper procedure during cleaning operations.	Potential flow restrictions and system contamination.	Institute adequate personnel training on cleanliness levels and strict adherence to contamination control procedures. Ensure 100% inspection subsequent to all tank entries.
9	Oxidizer Tank Assembly	A	Torn ring baffle web.	LOX impact during fast fill operation.	Possible baffle failure with subsequent system contamination.	Ensure that LOX fill procedures specify a "slow fill" rate only. Incorporate redesign changes to strengthen the baffle in the fill inlet area.

TEST HARDWARE, END ITEMS, AND STRUCTURAL COMPONENTS

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	All Hardware	A	System invalidation due to unplanned events and/or modifications.	Adequate retest requirements not specified.	Inadequate retest of the disturbed system can result in mission loss.	Institute "Positive Statement" retest requirements and provide 100% quality inspection coverage during retest.
2	Contract End Items	B	Hardware end items not conforming to contract specification.	Systems and installation drawings not conforming to specifications and/or other contract requirements.	Cost and schedule impact.	Complete a First Article Configuration Inspection (FACI) on the hardware as early as possible in the production phase to find and correct any existing nonconformance with contract requirements.
3	Contract End Items	D	System inadequate to verify the conformance of articles to drawing requirements during assembly.	Improper methods of releasing drawings.	Unscheduled rework.	Ensure that engineering planning is established to release drawings in accordance with MIL-D-70327 and at tier levels compatible with manufacturing effort.
4	Contract End Items	D	Numerous and frequent accidents resulting in damage to stage and associated equipment.	Lack of personnel training and/or supervision, inadequate operating procedures and safety controls, and noncompliance with established procedures.	Added cost and schedule impact.	Survey contractor to ensure that an adequate system is established for training and certification of personnel, control of facilities equipment, and a strong safety program.

TEST HARDWARE, END ITEMS, AND STRUCTURAL COMPONENTS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
5	Exposed Hardware	E	Susceptibility to damage (dings, dents, scratches, etc.).	Protective covers not used.	Costly repairs, unscheduled maintenance, and schedule slippage.	Install protective devices on hardware susceptible to damage. Emphasize the importance of observing precautions.
6	Pneumatic Components	B	Contamination and erosion.	Inadequate cleanliness and fabrication control requirements.	System contamination and leakage.	Refine cleanliness requirements and improve fabrication control disciplines.
7	Qualification and Engineering Test Hardware	B	Identification and control to prevent use as flight hardware.	Items not marked to identify them as test hardware.	Unqualified and nonflight worthy hardware used as flight hardware.	Positive marking identification of all test hardware should be conducted as soon as an item is selected for test. Establish a serial number control system to prevent unauthorized installation. Establish bonded areas for storage purposes.
8	Qualification Test Hardware	D	Test environments not compatible with mission environments.	Inadequate research of probable environmental conditions.	Failure to meet designed requirements.	Test all hardware in the environmental ranges to which it will be exposed.
9	Tungsten Inert (TIG) Welded Hardware and Structures	B	Numerous welding defects.	Insufficient rigidity of welding fixture.	Need for costly rework or failure of structure and hardware.	Where proximity requirements are very critical, movement of the work rather than the welding head should be the basic tool design approach for TIG welding.

TEST HARDWARE, END ITEMS, AND STRUCTURAL COMPONENTS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
10	Various Components	D	Improper installation of components.	Human error.	Possible loss of mission.	Future designs should be such that there will be no question as to the proper method of installation. Where problems exist, implement color coding requirements and instructions for installation.
11	Various Functional and Structural Components	D	Stress Corrosion.	Use of materials susceptible to stress corrosion.	Failure of the affected component, with effects ranging from test delay to mission loss.	Minimize use of corrosion susceptible materials. Require Class I drawings defining the sensitive components, inspection criteria, and inspection frequency.

UMBILICALS

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Carrier Retract Reconnect Assembly	A	Carrier retaining latch disengages prematurely allowing carrier locking pawl to hit the vehicle.	Weak spring in the latching mechanism.	Structural damage.	Redesign latching mechanism with a modified pin release flange and add a stop to limit travel of the flange.
2	Stage Umbilicals	B	Misalignment of quick disconnects.	Improper alignment tools for ground and vehicle halves of umbilical plates.	Damage to disconnects and loss of ground-to-vehicle services.	Caution personnel on the use of proper alignment tools. Add inspection points when disconnects are installed subsequent to static firing. Perform alignment checks whenever disconnects are remated.
3	Umbilical Carrier Reconnect Assembly	A	Slow and incomplete travel of carrier retract.	Improper spring rate requirements causing a need for more retract force than available.	Failure to operate within specifications.	Modify qualification and acceptance test procedures to require the measured forces for line retraction and extention to be accurate within specified limits. Institute inspection points during carrier spring assembly.
4	Umbilical Locking Mechanism	A	Locking pawls of interface connecting mechanism drop from the retracted position.	Damaged pins which had been subjected to directional loads not experienced under normal conditions.	Inability to keep the umbilical connection mated.	Initiate modification to the pin release flange and add a stop to limit travel of the flange to alleviate excessive directional loads.

VALVES AND MODULES

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Ball Valve	A	Leakage between body and flange.	Creased O-rings occurring during assembly.	Out of tolerance operation.	Initiate tighter inspection controls during vendor assembly. Provide for acceptance testing of components prior to installation.
2	Ball Valve	A	Leakage during pressurization.	Seat wearout due to continuous use.	Out of tolerance operation.	Establish a preventive maintenance schedule to replace seats at regular intervals.
3	Check Valve	C	External helium leakage.	Insufficient metal to metal bottoming between valve body and retainer during assembly.	Depletion of helium supply.	Ensure that assembly instructions are adequate and specify that bottoming of valve body to retainer must be accomplished. Institute inspection at this point.
4	Check Valve	A	Internal lock pin sheared.	Undersized lock pin; inadequate design.	Inlet port blocked by poppet.	Ensure that system is designed to prevent the use of unnecessary hardware installations.
5	Check Valve	A	Sticking valve.	Improper assembly after cleaning.	Failure to perform function.	Initiate tighter surveillance during rework operation.
6	Check Valve	A	Reverse seat leakage.	System contamination.	Improper valve operation.	Incorporate use of valve seats with harder materials that are less susceptible to contamination impregnation. Utilize metal-to-metal seats where possible. Ensure that procedures and specifications are adequate to prevent system contamination.

VALVES AND MODULES (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
7	Chilldown Shutoff Valve	C	External leakage between actuator and microswitch housing.	Fatigue cracks and bellows failure due to metallic contamination on the poppet guide bore.	Degraded valve performance.	Use a Teflon guide to prevent metallic particle contamination. Select stronger body materials or "beef-up" existing material to prevent fatigue cracking.
8	Cold Helium Dump Module	C	Main poppet valve fails to return to the closed position.	Friction between seal and poppet guide.	Failure to hold pressure.	Ensure that poppet guide and seat material tolerances are adequate to prevent frictional forces.
9	Cryogenic Butterfly Valve	C	Incorrect valve position indications.	Not built for or tested at operation environment.	Test delay to determine actual position.	Ensure that hardware is built for and tested to the environment in which it will be used.
10	Fuel Prevalve	A	Lubricant used instead of LOC-TITE locking compound.	Human error.	Internal gate seal nut torque relaxation with subsequent back-off of nut.	Institute tighter vendor inspection controls and implement personnel training in the assembly of fluid components.
11	Fuel Tank Pressurization Control Module Assembly	C	Torn seat and worn poppet guide.	Use of improper tooling during outlet orifice calibration.	Excessive leakage past the inlet check valve.	Ensure calibration procedures identify the specific tool to be used for each operation and that correct test order will verify proper operation.

VALVES AND MODULES (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
12	Gas Generator Ball Valve	D	Stripped threads on Q.D. coupling.	Inadequate thread length.	Fuel leakage at ball valve inlet drain.	Change drawings to specify use of longer ball valves.
13	Gas Generator Fuel Purge Check Valve	D	Test plate installed incorrectly.	Personnel error.	Valve will not meet minimum specified flow requirements.	Caution technicians and inspectors to adhere strictly to test plate installation procedures.
14	Gas Generator Oxidizer Valve	D	Restricted gas generator flow.	Poppet retaining ring not made to drawing specifications.	Insufficient hot gas for fuel and oxidizer turbine operation.	Implement 100% inspection at vendor facility to ensure parts are manufactured according to drawings.
15	GH_2 Pneumatic Valve	C	Bent valve body.	Improper handling.	Poppet will not mate against valve seat.	Instruct personnel on the proper handling and care of parts.
16	Hand Valve	A	Incomplete closure.	Facility contaminants adhering to the seat.	Leakage; out of tolerance operation.	Initiate preventive maintenance to ensure system cleanliness level is maintained. Periodic inspections should be included. System and component design should be primary means of obtaining equipment capable of proper operation.
17	Helium Flow Control Valve	A	Fails to indicate closed position.	Moisture corrosion on the indicator switch.	Possible launch scrub.	Institute procedures for moisture-proofing of flow control valves.
18	Helium Solenoid Valve (3-way)	D	Metallic contamination in connector.	Misalignment while mating plug to solenoid connector.	Solenoid fails to actuate.	Revise field manual to include special instructions for mating plug to solenoid connector.

VALVES AND MODULES (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
19	Helium Vent and Shutoff Valve.	A	Failure to transmit open indication signal.	Valve micro-switch corrosion.	Incorrect output leading to launch delay or scrub.	Replace fill and shutoff valve with a check valve to enhance proper operation.
20	Ignition Monitor Valve (IMV)	D	Internal leakage.	Incorrect poppet adjustment; human error.	Premature opening of main fuel valve.	Ensure poppet adjustment is correct at initial setting and perform tests to verify that initial adjustment is not disturbed.
21	Ignition Monitor Valve (IMV)	D	Deformation of bolt plunger tip.	Inadequate procedures resulting in overpressurization of the IMV control port.	Probable engine shutdown.	Revise ignition monitor valve test procedures and implement modifications to ignition monitor valve test tools presently being used.
22	LH_2 Continuous Vent Module	C	Excessive leakage at the bypass shutoff valve actuator and valve body.	Inadequate purge causing freeze-up of the valve and damage to the seal.	Inability to maintain proper flow rate.	Ensure purge flow rate is compatible with the requirements of the module.
23	LH_2 Vent and Relief Valve	C	Excessive leakage past piston rod threads.	Inadequate staking and retention methods.	Possible locking of the main valve in the closed position.	Change retention methods from staking to locking with a castle nut and cotter pin.
24	LH_2 Vent Valve	B	Slow actuation time.	Contaminated helium supply.	Degraded valve performance.	Install filters at the helium supply outlet and perform periodic scheduled sampling inspections of the helium. Cycle and purge valves prior to functional testing to remove trapped contamination.

VALVES AND MODULES (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
25	LOX Fill and Drain Valve	A	Major internal leakage in the closed position.	Cracked main seal.	Explosive environment; fire hazard.	Redesign main seal. Previous redesign incorporated a triple seal arrangement consisting of an external static seal, an internal dynamic seal, and a pressure backup seal.
26	LOX Prevalve	A	Main seal retainer locknuts loose.	Improper design.	Provides a source of contamination and possible ingestion into the LOX pump.	Implement design change to provide for positive locking of the seal retraction mechanism (lockwire retainer nuts). Incorporate test procedures to ensure proper operation.
27	LOX Prevalve/ Fuel Prevalve	A	Prevalves close at the same time the main valves close.	Faulty delay timers.	Loss of required closing delay after main valve closure can result in possible turbopump cavitation and subsequent explosion.	Delete usage of electrical delay timers and incorporate an orifice in the prevalve pneumatic actuation line to provide delayed closure.
28	LOX Shutdown Valve	C	Valve hang up in the open position.	Leakage past both open and close seals resulting in no delta pressure for disengaging the valve locking device.	Failure to operate.	Modify valve configuration by adding a vent between the open and close port seals to allow a delta pressure to be attained.

VALVES AND MODULES (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
29	LOX Shutdown Valve	C	Cracked poppet.	Use of non-annealed poppet material.	Failure to operate within specification.	Incorporate use of annealed poppet material to prevent cracking and warping.
30	LOX Tank Pressurization Control Module.	C	Excessive internal leakage past the shutoff valve.	A chipped main poppet seat (Mylar material).	Out of tolerance operation.	Use of a poppet seat composed of Polyimide material has proven to be effective.
31	LOX Tank Relief Valve	A	Valve indicator fails to show proper position during functional test.	Improper assembly of switch resulting in a worn switch shaft.	Test delay to determine actual position of valve.	Implement personnel training and more stringent quality controls during switch assembly. Ensure that assembly procedures and drawings clearly define proper assembly installations and techniques.
32	LOX Tank Shutoff Valve	C	External leakage at flange joint.	Scratch on sealing surface and high porosity of casting.	Failure to function properly.	Expand source inspection requirements to include a 100% inspection of all Marman flanges.
33	LOX Tank Vent and Relief Valve	A	Valve actuator gear clutch spring lodged between two gears.	Unnecessary spring redundancy for proper valve operation.	Leakage through valve.	Ensure vendor design is adequate to accomplish function without incorporating unnecessary components.
34	LOX Vent and Relief Valve	A	Excessive vent line leakage.	Seals damaged due to contamination introduced into the system by the GSE gaseous supply.	Loss of control pressure.	Incorporate valve seats that are less susceptible to contaminants. Ensure GSE contamination procedures and controls are adequate to preclude stage contamination.

VALVES AND MODULES (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
35	LOX Vent Valve	B	Open indication switch fails to operate.	Moisture in the switch actuator causing freezing during chilldown.	Inability to determine actual position of vent valve.	Redesign the switch by relocating the bellows to seal off all moving parts to prevent moisture entrapment.
36	LOX Vent Valve	B	Valve fluctuation between open and closed positions.	Pneumatic pressure variations caused by the length of the vent line.	LOX tank pressure fluctuation resulting in excessive LOX boiloff. Vent valve reseats at lower than specified pressure.	Modify vent valve by adding a surge chamber and a dash pot (double plenum and orifice) to dampen pressure fluctuations.
37	LOX Vent Valve	B	CRES diaphragm leakage.	Gold plating flaking or corrosion caused by entrapped plating solution residues.	High aneroid bellows pressure; vent valve operating pressure out of specification.	Ensure that manufacturing procedures are adequate to prevent the entrapment of plating solution residues through cleaning and purging methods and subsequent inspections. Institute periodic inspections of valve to ensure proper aneroid bellows operation. Ensure bellows material is compatible with CRES diaphragm and plating solutions.
38	LOX Vent Valve	B	Main poppet leakage.	Contamination lodged on flat surface of poppet seal during valve installation.	Major vent valve leakage; loss of tank pressure.	Utilize protective enclosures (tents) during installation or removal of valves from system. Revise procedures and specifications to require "Flow Cycling" of the valve to remove suspected contamination.

VALVES AND MODULES (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
39	LOX Vent Valve	B	Solenoid connector shorted.	Moisture entering through a cracked solder joint on the electrical connector.	Solenoid fails to operate; inability to operate vent valve.	Institute use of welded joints rather than soldered joints. Caution personnel on the proper handling of solenoid valve connector assemblies.
40	LOX Vent Valve	B	Seat leakage.	Metal particle contamination on valve seat.	Inability of valve to cycle to a completely closed position.	Revise test procedures associated with leak-checking the vent valves to require "Flow Cycling" to eliminate contamination prior to valve removal. Include a requirement for a tent-type enclosure during valve installation or removal.
41	Main Fuel Valve	D	Fuel in position indicator housing.	O-ring damaged during assembly.	Fuel leakage; erroneous valve position indications.	Initiate tighter vendor inspection controls during O-ring installation.
42	Main Oxidizer Valve	D	Detonation of LOX and hydrocarbon contamination.	Inadequate documentation to control and ensure part cleanliness and identification.	Possible engine explosion.	Change cleaning, packaging, and assembly documentation to ensure parts are LOX clean and verify through inspection.
43	Main Oxidizer Valve	D	Moisture in valve.	Engine drying not performed after static firing; inadequate procedures.	Rusty gate shaft ends.	Ensure that a vacuum drying operation is performed subsequent to fill valve operation.

VALVES AND MODULES (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
44	Mainstage Control Solenoid Valve	D	No response upon command.	Corrosion between pins and case.	Short; solenoid will not energize.	Megger check all solenoid valves in the field on a periodic preventive maintenance schedule.
45	Modulating Flow Control Valve	E	Defective modulating flow control valve.	Improper adjustment of the GSE cooling unit.	Failure to control flow.	Instruct operating personnel in the proper adjustment of unit.
46	Override Solenoid Valve	C	Fails to actuate in cryogenic environments.	Pin hole leak in hermetic seal.	Freezing; loss of solenoid function.	Ensure process controls are adequate to prevent pin hole leaks. Institute inspection using a mass spectrometer.
47	Pneumatic Actuation Control Module	C	Leakage in open and/or closed position.	Inadequate seal design.	Failure to function properly.	Ensure that qualification testing will prove design requirements of the component. Qualify by test only.
48	Pneumatic Power Control Module	C	Lockup pressure above specification.	Contamination combined with a small movement of the regulator lockup device.	Improper pressure output.	Use inlet filters that will preclude the entrance of contamination. Use anodized poppets and seats to minimize high flow/high velocity damage.
49	Pneumatic Power Control Module	C	Helium leakage in closed position.	Inadequate seal design.	Failure to function properly.	Ensure that qualification testing will prove design requirements of component. Qualify by test only.

VALVES AND MODULES (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
50	Propellant Control Module (APS)	C	Contamination.	Reaction of APS fuel with cleaning agent (Freon-MF).	Slow engine valve actuation.	Ensure that cleaning procedures are adequate, and utilize a compatible cleaning agent such as unsymmetrical isopropyl alcohol.
51	Relief Valve	C	Leakage past valve outlet.	Valve flange made of inadequate metal.	Failure to function properly.	Select proper material and prove the integrity by test prior to production.
52	Relief Valve	A	Audible leakage past seat.	Use of excessive LOC-TITE thread compound.	Loss of GN_2 supply.	Institute tighter manufacturer assembly and inspection controls. Ensure personnel are trained in proper use of thread compounds.
53	Relief Valve	B	Leakage past seat.	Seat pitted by contamination.	Premature operation of vent valve.	Implement tighter inspection controls for cleanliness levels of pneumatic systems.
54	Relief Valve	B	Low relief pressure.	Worn sealing O-ring.	Inability to maintain required pressure level.	Institute a preventive maintenance program to provide for O-ring changeout at regular intervals.
55	Relief Valve	A	Damaged pilot poppet and loose balls on main poppet assembly.	Normal vibration.	Fails to relieve and reset at specified pressures.	Ensure valves are qualified using vibration specifications simulating in-service condition.
56	Relief Valve	C	Split diaphragm.	Inadequate material and design of the diaphragm.	Internal leakage.	Ensure component environmental operation through extensive qualification testing.

VALVES AND MODULES (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
57	Relief Valve	A	Defective ball bearing.	Improper assembly.	Inability to adjust relief setting.	Establish training to ensure personnel are aware of proper ball bearing insertion procedure.
58	Relief Valve	A	Broken O-ring.	Back pressure, popping the valve off seat.	Leakage at all pressures.	Ensure procedural steps are compatible with proper operation of equipment.
59	Relief Valve	C	Valve wearout under cryogenic applications.	Unacceptable, unqualified valve design for cryogenic environment.	Gas leakage.	Ensure valve design is compatible with desired usage environment and prove integrity of valve through qualification testing.
60	Shutdown Valve	C	Cracked poppet.	Use of non-annealed poppet material.	Failure to operate within specification.	Institute use of an annealed poppet to prevent cracking and warping.
61	Solenoid Ball Valve	A	Failure of electric actuator.	Inadequate design; actuator shaft binding due to split washers.	Ball valve will not completely open or close.	Replace electric actuator with a single ported flange connected to the outlet of a 3-way 2- position solenoid valve.
62	Solenoid Operated Valve (3-way)	D	Contamination in valve.	Inadequate venting procedures for purging contamination.	Leakage through valve.	Add note to field manual to change venting procedure and specify a leak check to preclude contamination and leakage in flight.
63	Solenoid Valve	A	Leakage past the main seats.	Seat deterioration due to heat build-up during long periods of valve energization.	Out of tolerance operation.	Replace seats with high temperature (Vespel) material.

VALVES AND MODULES (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
64	Solenoid Valve	F	Rust deposits.	Inadequate O-ring seal.	Inoperative valve.	Incorporate adequate manufacturer designs, processes, and inspections. Replace O-rings on regular preventive maintenance schedules.
65	Solenoid Valve	A	Failure to close.	Previous rework causing increased armature gap.	Inability to shutoff flow.	Reinspect reworked parts to ensure that all tolerances are to specification.
66	Solenoid Valve	B	Failure to close.	Poppet spring out of adjustment.	Inability to terminate flow at desired time.	Perform a functional checkout prior to installation, and monitor for conformance to specifications.
67	Solenoid Valve	C	Failure to open.	Lock washer improperly placed under jam nut during servicing.	Inability to operate upon command.	Provide for personnel training and inspection points to preclude improper servicing.
68	Solenoid Valve	B	Pull-in voltage out of specification.	Improper modification adjustment.	Valve would not open flow port.	Establish a training program for personnel and follow-up with a technical manual to provide procedures for proper valve servicing.
69	Solenoid Valve	B	Leakage past seat.	Seat installed backwards.	Inability to control flow.	Revise assembly procedure to provide for visual inspection of seat with a 10x scope.
70	Solenoid Valve	B	Continuous venting.	O-ring nicked and nylon seat cracked and worn.	Inability to supply required downstream pressure.	Institute a preventive maintenance program to provide for O-ring and seat replacement at specified intervals.

VALVES AND MODULES (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
71	Solenoid Valve	B	Cracked solder joint at electrical connector.	Improper handling.	Short circuit.	Institute use of welded joints rather than soldered joints. Maintain strict adherence to handling procedures.
72	Solenoid valve	B	Water in valve.	Humidity in valve actuation lines; inadequate purging procedures.	Freezing of valve in a cryogenic environment.	Purge system until an acceptable dew point level is attained.
73	Start Tank Discharge Valve	D	Cracked bellows.	Inadequate thickness of bellows seal and debonding of plastic bellows seal due to rust contamination.	Leakage through valve.	Change drawings to increase thickness of seal and to add inner and outer seal retaining rings. Initiate use of an organic sealant for valve body and hard chrome plate wear surfaces.
74	Start Tank Discharge Valve	D	Aluminum oxide contamination.	Chemical corrosion.	Reverse leakage through valve.	Revise leak test method and specify usage of an organic sealant to prevent corrosion effects.
75	Start Tank Fill Valve	D	Moisture in valve.	Vacuum drying not performed after static firing; inadequate procedures.	Leakage through valve.	Ensure that a vacuum drying operation is performed subsequent to fill valve operation.

VALVE AND MODULES (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
76	Tank Pressurization Control Module	C	Solenoid valve fails to return to closed position under normal force.	Excessive pressure on the poppet dynamic seals.	Excessive closing force required for valve operation. Uncontrollable output pressure.	Friction can be reduced by using a single seal made of material with a lower friction coefficient.
77	Vent and Relief Valve	C	Leakage.	Contamination due to inadequate cleaning procedure after rework and prior to installation.	Failure to function properly; continuous venting.	Impose strict requirements to prevent contamination from entering the valve during rework, installation, and testing.
78	Vent and Relief Valve	C	Leakage past the seat.	Contamination.	Failure to function properly; continuous venting.	Refine cleanliness requirements and improve fabrication control disciplines.
79	Vent and Relief Valve	A	Valve fails to relieve the fuel tank pressure.	Servopoppet contamination during assembly.	Valve malfunction with possible fuel tank damage.	Institute additional inspection points during manufacture. Ensure personnel are properly trained and certified for pneumatic systems assembly.

MISCELLANEOUS

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
1	Auxiliary Propulsion System (APS)	C	Fuel bladder leakage.	Torn bladder due to weld burrs and inadequate inspection.	Depletion of APS fuel.	Institute 100% inspection of all diffuser welds after fabrication.
2	Environmental Control System (ECS)	E	Loose B-nut on coolant line.	Human error.	Coolant pump inlet and outlet pressures below allowable limits; leakage.	Initiate training of personnel in the proper torquing of B-nuts.
3	Environmental Control System (ECS)	E	Numerous problems when converting from H_2O/ Methanol to Oronite coolant.	Inadequate engineering being performed on "In Process" changes	Flight end items used as a "Test Bed" for performing the engineering, rather than a test bed to verify the change.	Changes of any magnitude should be preengineered to preclude the use of flight hardware as an engineering model.
4	Filter	A	Crack in filter housing.	Stress corrosion.	Filter leakage.	Revise heat treating procedures for filter housings. Ensure through inspection that housing is at proper temper during manufacturing, making it less susceptible to stress corrosion.
5	Fuel High Pressure Duct Flange	D	Flange made of wrong type aluminum.	Receiving Inspection not adequate to verify proper material properties.	Flange breakage during straightening operations.	Revise receiving inspection procedures and implement 100% non-destructive testing verification of material.

MISCELLANEOUS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
6	GN_2 Supply Pressure (Test Supply)	D	Oil contamination.	Piston failure in compressor.	Teardown and cleaning of test console and engine systems.	Sample test fluid before and after engine checkout. Redesign system to delete use of piston compressor and add filters.
7	Impeller Fan	F	Cracks in fan blade.	Flutter condition existing at blade leading edge.	Blade breakage.	Initiate investigation into possible usage of different material for blades. Implement inspection of blades on a regular preventive maintenance schedule.
8	Inaccessible Areas	B	Entrapment of foreign objects (bolts, nuts, washers, etc.).	Lack of adequate inspection.	Costly repairs, unscheduled maintenance, schedule slippage.	X-ray inaccessible areas after assembly operations. Rotate stage with an amplified sound detecting system installed.
9	Latch Shaft	B	Galled locking shaft.	Nonlubrication of shaft; inadequate procedural requirements.	Inability to remove LH_2 disconnect.	Revise drawings to provide for specific callout on parts requiring lubrication.
10	Latching Springs	F	Broken spring.	Marginal spring design.	Inoperative spring assembly.	Initiate spring and/or spring assembly redesign. Ensure proper operation prior to production.
11	LOX Dome	D	Metallic contamination.	Inadequate inspection during fabrication, assembly, and installation.	Possible engine damage.	Revise inplant inspection procedures to include an additional inspection operation after fabrication and prior to installation. Ensure cleaning procedures are adequate.

MISCELLANEOUS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
12	LOX Sump Baffles	B	Bent and broken baffles.	Shock and fatigue resulting from fast LOX loading.	Inability to prevent sloshing and swirling of LOX. Provides source of contamination for pump ingestion.	Institute use of stronger baffles. Ensure that LOX fill procedures specify a "slow fill" rate.
13	Manufacturing Operations	D	Drilling operations in welded systems.	Inadequate manufacturing planning.	Contamination.	Perform all drilling operations prior to welding. Where this is not possible, purge system and X-ray when integrity might be questionable.
14	Material Control	D	Items being made of wrong material.	Inadequate vendor controls, receiving inspection, and material identification.	Ranges from test delay to mission loss.	Upgrade packaging requirements, and institute 100% inspection by methods such as eddy current. Revise controls, receiving inspection, and warehousing requirements.
15	O_2/H_2 Burner Assembly	C	A burned hole in the spool of the combustion chamber.	Improper match of the orifices on the injector plate due to improper calibration.	Complete destruction of burner assembly.	Ensure that injector plates have properly calibrated orifices and are tested prior to release.
16	Pneumatic Checkout Rack	A	Reversed outlet lines.	Design drawing error.	Incorrect system pressurization.	Caution design personnel to check and recheck drawings. Institute use of design checkers.

MISCELLANEOUS (Continued)

No	Hardware	Ref Code	Problem	Cause	Effect	Remarks/Suggestions
17	Retrorocket Motor	A	Wall thickness too thin and cases creased.	Improper manufacture.	Rupture of water case.	Institute tighter manufacturing inspection controls.
18	Vibration Isolators	C	Debonding of isolators from aluminum.	Marginal process steps during initial bonding.	Failure to isolate; loss of structural integrity.	Use of improved process methods, stricter quality controls, primers with greater bonding characteristics, and rigid inspection controls, should preclude debonding problems. Also, pull tests should be performed to ensure proper bonding.

SECTION 3

TECHNIQUES

TECHNIQUE INDEX

TECHNIQUE INDEX

1 ACOUSTICAL EMISSION TECHNIQUE

Ref. Code A*

PURPOSE: Detection of crack propagation in metal.

A new technique for the detection of the propagation of cracks in metals has been developed. This technique, referred to as Acoustical Emission, operates on the principle that each metal will generate a resonant frequency wave length when the parent metal is vibrated. Any vibration from the resonant wave length indicates the presence of a disrupting factor, e.g., crack propagation.

It should be noted that this technique has not been thoroughly developed; however, the basic concept is feasible and only little further development would be necessary for applicability to this and other programs.

*For reference code identification, refer to Introduction, page 2.

2 ASSESSMENT, REPORTING, AND MONITORING OF FAILURES

Ref Code A

PURPOSE: Provides corrective action support for defective hardware.

The basic philosophy of this system is to analyze each failure to determine cause and initiate necessary changes to preclude recurrence.

Failure information is collected during manufacturing and testing of stages and associated ground support equipment. These failures are documented on the Unplanned Event Record (UER). The UER is part of the Launch Vehicle Branch integrated record system and provides the means for formal failure analysis and resolution.

Each UER is tracked as an unresolved problem until the required nonrecurrence action is implemented. Additionally, the failures are classified by criticality code with respect to impact on the next scheduled launch. If program nonrecurrence action cannot be implemented prior to a specific launch, each unresolved failure is assessed by a Management Assessment Board. The "board" provides the initial rationale for risk assumption and work around procedures.

The continuous monitoring and assessment of unresolved failures provide the necessary controls to effect a design mature stage. The formulation of a unique "board" to assess unresolved failures, that cannot be corrected prior to launch, in a routine and timely manner, is considered a program innovation that should be established for all future programs/contractors.

3 AUTOMATION OF FLOWMETER CALIBRATION

Ref. Code D

PURPOSE: Use of Saturn computer program and calibration curves.

The calibration of flowmeters was completely automated. Initial calibration data is reduced by data processing using a special FORTRAN program, and converted into calibration curves. Subsequently, calibration data is taken for three points on each curve and reduced on a programmed electronic calculator giving the percent difference of the original curve data from the current test data. If this percent is within acceptable limits the curves are validated for another calibration interval. This concept replaced a previous program of performing a manual calculation of each data point and a physical plotting of the data into a curve. Time for flowmeter calibration has been reduced from 8 hours to 0.75 hour per curve.

4 CALIBRATION INTERVAL ADJUSTMENT PROGRAM

Ref. Code D

PURPOSE: Test equipment calibration.

A calibration interval adjustment program was developed and implemented. The program adjusts the calibration interval of each item of test equipment based on its "as found" tolerance and/or condition at each calibration. The program is easy to administer because of the simplified decision making output planned into the interval adjustment charts. The charts are based on technically sound statistical principles eliminating a previous system of applying personal judgment only. The program was needed to eliminate inadequate decision making ability and during the past three years, the average calibration interval has doubled while the "as found" in-tolerance frequency has improved from 79 percent up to 90 percent.

5	CONTROL OF TUBE FLARE FABRICATION	Ref. Code A

PURPOSE: Controlling machine performance.

An engineering analysis of the tube flaring problem (high rejection rate on finished hardware) indicated that inspection and control measures should be established as far upstream in the fabrication process as possible. Analysis indicated that a highly reliable method of controlling the machine performance was the answer to the problem.

An engineering evaluation of the Leonard Machine design disclosed a deficiency in the design of the spindle bearing and seal application. It was necessary to remove the bearings, clean, repack, and adjust them before each certification period. Repeated sampling of the machine performance proved that the machine satisfied the repeatability requirements for the duration of the certification period. By implementing a system based on certified machines and certified operators, the leakage rate on tube flares has been reduced to approximately 2 percent of the installed hardware. Rejection of finished hardware due to flares before installation was reduced to less than 3 percent.

6	CORRECTIVE ACTION CONTROL	Ref. Code B

PURPOSE: Provide data for recurrence control action.

The Corrective Action Control Center, generally referred to as the "Action Center," was established to provide a central control point to display and monitor all significant problems.

These problems are displayed on a "Significant Problem Constraint Board" which identifies the problem relative to the stage, GSE, milestones constrained, and current status of corrective/recurrence control action. A Contractor Quality Control representative is assigned each problem and charged with the responsibility for tracking corrective action progress through a satisfactory conclusion. Repetitive conditions can be readily detected and appropriate action initiated in a timely manner. Such a system is an effective management tool in that current information relative to problems and corrective action proceedings are available through a single point of contact.

7	DATA REDUCTION BY COMPUTER	Ref. Code D

PURPOSE: Permit rapid and accurate data reduction of calibration data.

In excess of 30 data processing programs have been written and implemented to permit rapid and accurate data reduction of calibration data. Data reduction eliminated previous manual calculations, permitting a substantial reduction in calibration time. These concepts are constantly being applied to more equipment. Industry-wide savings can be obtained through these principles.

8	DENT MEASURING TECHNIQUE	Ref. Code A

PURPOSE: Determination of depth of dents in spherical surfaces.

A special technique for exact determination of the depth of dents in spherical surface on hard-to-reach surfaces was necessary for evaluation of their severity.

A technique has been developed by using a molding material to fill the dent, removing material after curing and finally, accurately measuring the molded material by means of a comparator to determine the exact contour and depth of the dent.

9 DEVELOPMENT OF ENGINEERING LANGUAGE COMPUTER TEST PROGRAMS

Ref. Code H

PURPOSE: Development of an engineering language computer test program.

An engineering language computer test program known as ATOLL (Acceptance, Test, or Launch Language) was developed to eliminate the necessity for manual conversion of engineering data to machine language.

The ATOLL program provided a language for use in automatic checkout and launch testing of the stage or vehicle completely independent of local consideration (i. e., checkout or launch equipment and location), and utilized the knowledge of the launch vehicle test engineer for automatic checkout and launch testing.

It also established criteria for development of a single document which satisfied the following needs:

a. A detailed test procedure in automatic checkout and launch testing.

b. A test program for input into the automatic checkout and launch test system.

c. A test review and evaluation document for plant representatives and project offices.

d. A checklist for government inspection teams for verification of contractor automatic test performance.

9 DEVELOPMENT OF ENGINEERING LANGUAGE COMPUTER TEST PROGRAMS (Continued)

ATOLL programs provided advantages such as reduced programming costs, increased test effectiveness, higher operational efficiency, and automatic checkout and launch test systems, which resulted in schedule and manpower savings, and reduced the number of errors.

10	EDDY CURRENT TECHNIQUE	Ref. Code A	10	EDDY CURRENT TECHNIQUE (Continued)

PURPOSE: Refinement of various nondestructive testing methods.

Throughout the program, problems concerning unique hardware conditions have arisen that required the development or refinement of various nondestructive testing methods.

For eddy-current testing, the word "flaw" has a much wider meaning than it does for the other forms of nondestructive testing. Not only can cracks, voids, and fissures be detected, but also differences in alloy, conductivity, hardness, grain size, inclusion content, thickness of plating, etc. The information concerning a flaw is obtained from the change in impedance of a test coil supplied with an alternating current of suitable frequency. The coil induces a varying field in a part under test which in turn generates eddy currents in the part. The eddy currents react on the exciting coil and affect its impedance. These impedance variations can be analyzed; their magnitude and phase yield information concerning the type and severity of the flaw.

Two general types of coils are in common use. One is a cylindrical coil, called a feed-through coil, through which the test part passes. The other type is a small coil which can be placed on the surface of the part and is called a probe coil. Feed-through coils are particularly suited to the testing of cylindrical objects such as barstock tubing. Probe-type instruments are usually used for the detection of defects such as seams and cracks, which cause changes in conductivity.

Eddy current inspection techniques have been refined or developed to provide for rapid, accurate inspection of the following:

a. Characteristics of titanium weld wire

b. Thickness measurements of stainless steel tubing

c. Detection of surface cracks in steel spherical bearings and housings

d. Detection of surface cracks in nonmetallic ablative coatings.

11 ELECTRICAL CONDUCTIVITY TECHNIQUE

Ref. Code A

PURPOSE: Test to determine specified heat treat of metal.

Due to the possibility of error in the area of heat treat, there arose a need for a method of testing to determine the specified heat treat. Existing test equipment has been adapted for rapid verification of heat treat conversion of aluminum from 7075-T6 to 7075-T73. The technique has further been refined to provide for a rapid determination of the electrical conductivity in small and odd shaped 7075-T73 aluminum fittings.

12 ELECTROLYTIC LEAK DETECTION

Ref. Code A

PURPOSE: Leak detection process for large diameter tanks.

The tremendous size of the Saturn propellant tanks dictated that the use of standard techniques for leak detection was impractical. Each standard system was analyzed for its adaptability to meet the requirements imposed by Saturn tanks. However, in each instance, the standard techniques proved to be unsuitable.

To overcome the limiting factors imposed by the standard leak detection systems, a unique system, devoid of personnel inspection operations, was developed. The Electrolytic Leak Detection System is extremely simple in components and operations. The system consists of adhesive-backed aluminum foil tape which is insulated from the tank by water soluble paper. A switching circuit connected between the foil and the tank indicates via a display panel when a deionized water leak occurs under the taped area. The relative size requirement of the S-IC tank (approximately 2,000 feet of weld seams) necessitates that the tape be broken into short individual strips to precisely locate a leak, but the system still maintains the capability of permitting the leak detection elements to be placed over all the desired areas prior to installation of the tank into the hydrostatic test position.

The Electrolytic Leak Detection System circumvents the prohibitive factors associated with existing standard techniques. The system, however, is highly reliable and economical notwithstanding its simplicity.

12 ELECTROLYTIC LEAK DETECTION (Continued)

The system components and operating techniques indicate that it could be readily adapted for inspection of any liquid pressure vessel system.

13 ELECTROMAGNETIC TECHNIQUE

Ref. Code
A

PURPOSE: Short range radar type measuring device.

Microwave equipment has been refined and developed to determine the thickness of the major assembly portions of the propellant tanks during chemical milling and subsequent operations. The microwave principle is essentially a short radar type of measuring device.

In order to maintain structural integrity and uniformity of these parts, assurance of proper thickness was required. Because of the large size of these parts, conventional means of measuring were not appropriate and no other known method was available.

14 EQUIPMENT QUALITY ANALYSIS / QUALITY MAINTENANCE TESTING

Ref. Code A

PURPOSE: Continuation beyond the "problem" hardware concept.

An Equipment Quality Analysis (EQA) Program has been designed to continue beyond the "problem" hardware concept. Although suspected or known hardware problems are thoroughly investigated, the EQA program is intended to reach beyond the "reason" for a particular problem's existence and to seek the latent "reasons" as to cause. This program has not limited itself solely to the confines of problem analysis. This program periodically investigates selected production hardware by random sampling of parts or components (procured or manufactured) which were originally scheduled for flight or ground support equipment. The sampled hardware is subjected to intensive laboratory analysis which range from a complete software package audit through hardware disassembly which may or may not be destructive in nature.

The primary purpose of this concept is to provide additional assurance of product integrity and reliability by serving as an adjunct to the reliability and failure analysis programs.

A natural outgrowth of this concept was Quality Maintenance Testing (QMT) as a part of the Quality Maintenance Program. This latter program extends the increased product assurance concept to reliability critical hardware (that hardware where failure could cause loss of crew

or vehicle). Primary emphasis is placed on the critical hardware which has not demonstrated any problems which would have subjected the hardware to scrutiny under any of the preceding programs.

The total concept of EQA as it presently exists has served to increase confidence that Saturn hardware will perform as designed with a high degree of reliability through elimination of latent defects. The combined EQA/QMT program correlated with in depth team reviews of suppliers' facilities, processes, and standards can be adapted with only minor modifications to increase confidence in hardware reliability on future programs.

15	FITTING OPTICAL TARGET FIXTURE	Ref. Code A

PURPOSE: Location of fittings on a spherical surface.

The Fitting Optical Target was developed in the Saturn program specifically for use in checking the location of the tank head assembly fittings. A family of Fitting Optical Targets (FOT) has been developed for the varying fitting configurations. The FOT provides a means by which the center point of an optical target can be quickly and accurately placed at the center of the fitting opening. The optical target can be rotated about its center providing sighting flexibility for the varying angular positions of the fittings. The displacement between the center of the target and the face of the fitting flange is established for each FOT according to engineering drawings. An adapter plate can be mounted on the FOT such that its plane is parallel to the surface plane of the fitting plane, thus, providing a surface from which the incident angle of the fitting to the gravity plane can be determined by means of a microptic clinometer.

The FOT was developed to replace the previous time consuming use of scales and necessary calculations, and to increase accuracy of the system.

16	FOUR AXIS MEASURING MACHINE	Ref. Code D

PURPOSE: Dimensional inspection of injectors.

A four-axis measuring machine was purchased primarily for use in the dimensional inspection of injectors and hardware which was fabricated on numerical controlled machines. Due to the weight and size of such items, the four-axis measuring machine reduced the number of setups required to perform dimensional inspection.

17 FREON INJECTION SYSTEM FOR LEAK DETECTION

Ref. Code G

PURPOSE: Use of preselected freon mixtures for operating in systems varying from a few pounds to 2500 psig.

Problems associated with in-system leaks necessitated action for the development of a freon injector. The two main features required of the system consisted of the preselecting of freon mixtures prior to pressurizing a system by the operator and the versatility of operating with systems varying from a few pounds to 2500 psig and flow rates of 25 to 800 cfm.

The freon injector has an air driven liquid boost pump which raises the freon from inlet pressure to 2500 psig. This high pressure freon is fed through an annin flow control valve to a mixing chamber in the system pressurizing line, utilizing the heat in the air to vaporize the freon.

A sample of the mixture is taken immediately downstream of the mixing chamber and is fed to an infrared freon analyzer instrument. The analyzer produces a signal proportional to the percent of freon in the sample. This signal is amplified and fed to an analog comparator. A second reference signal is controlled by the freon injector operator at the control panel. This controlled signal is fed to the analog comparator.

17 FREON INJECTION SYSTEM FOR LEAK DETECTION (Continued)

The signal from the analyzer and the signal from the freon injector panel are compared, and a new signal is generated which is proportional to the difference between these signals and causes the annin flow control valve to release more or less freon as required. The freon injector produces a mixture between 1 percent and 3 percent Freon 22 to the pressurizing media. The injector has provided for remote operation and has pneumatic provisions for both a "zero" sample gas and a "span" gas for calibrating the analyzer.

The operator controls are power switches, infrared analyzer flow control valves and regulators, and a pressure regulator for the air supply serving the annin flow control valve.

18 INFRARED THEORY AND ANALYSIS

Ref. Code A

PURPOSE: Evaluation of hardware for defects.

Electrical current flowing through an electronic component generates heat. This heat increases the temperature of the component and the variation in temperature is correlated to the power dissipation and to the current flow.

The heat radiated by the component is related to the temperature of the component. Hence, by measuring the infrared radiation emitted by the components in a circuit, the temperature profile of the circuit is obtained without interfering with the electrical or thermal characteristics of the circuit. To measure this infrared radiation, the infrared test station was used.

The infrared analysis technique described was needed to evaluate hardware for defects which could not be detected otherwise.

In future programs, "IR" could be used to investigate failures of electronic equipment, for evaluation of incoming items on a receival basis, and for process inspection.

19 IN MOTION X-RAY MACHINE

Ref. Code D

PURPOSE: X-ray of lines and ducts.

A capability was developed for a combined manual, semi-automatic and automatic "in motion" radiographic system for the inspection of circumferential welds. The "in motion" equipment permits X-raying a weld with one setup and one continuous exposure rather than rotating the part manually, thus, minimizing hardware handling problems, material handling damage, and personnel hazards.

The old method involved X-raying a small arc of the weld, rotating, and resetup of the part in a step-by-step procedure until the circumference of the weld had been X-rayed.

20 INSPECTION OF INACCESSIBLE AREAS — Ref. Code B

PURPOSE: Use of closed circuit TV with miniature camera to gain access to areas beyond reach of the human eye.

Closed circuit television equipment comprised of a miniature camera with magnifying lens was the technique employed to examine the drop through side of the "J" weld in the LH_2 tank. An automated miniature TV camera equipped with a 10 power magnification lens is mounted on a track at the nearest point possible above the "J" weld. The camera travels on the track around the entire circumference of the "J" weld area, viewing and recording the weldment on video tape. Any defects or indications are easily detected by the magnification and a permanent record of the inspection is provided by the video tape.

Previous inspection was performed by an individual using a borescope, a very inaccurate and time consuming method of performing the inspection, due to the proximity of the LOX tank dome to the LH_2 tank sidewall at the "J" weld. This technique, therefore, provided a much higher degree of confidence to ensure that the "J" weld was free of defects.

Similar techniques can be developed for unlimited use in the inspection of articles where physical access is limited or impossible for direct visual examination. An addition of an ultraviolet light to the TV camera could make it possible to perform Fluorescent Penetrant Inspection of welded surfaces in a similar manner.

21 INSPECTION OF SMALL DIAMETER LINE ASSEMBLIES — Ref. Code B

PURPOSE: Used for inspection of weld seams on the inside diameter of small lines.

An Inspection Test Fixture, comprised of a field indicator, calibration tool for calibrating fixture probe linear pot, low pressure (4-10 psi) bladder on fixture head, TV monitor, X-Y recorder and voltohmmeter, is used in the inspection of weld beads on the inside diameter of small pressure or fluid carrying lines ranging from 3 to 7 inches of diameter. The exact position of the Inspection Check Fixture, after insertion into the line assembly, is located by the field indicator. The small low pressure bladder is used to prevent inadvertent movement of the head after the fixture is in approximate position. A permanent magnet is mounted on the head of the check fixture. Thus, by moving the field indicator about the approximate position of the fixture and obtaining a peak meter reading, the weld seam undergoing inspection may be plotted by using a coordinate system. Through the closed circuit TV monitor a trace is made on the X-Y recorder showing the profile of the peaking and offset.

Before this technique and equipment were developed, it was impossible to inspect offset and peaking of weld beads inside small diameter lines.

This technique can be applied to great advantage in many areas where access is limited for direct visual examination of weldments and other critical surfaces.

22 LEAK DETECTOR FOR USE IN SPACE ENVIRONMENT

Ref. Code G

PURPOSE: To support orbital inspection and checkout operations.

With the advent of orbital workshops and future extended space missions, a need for a suitable leak detector to support orbital inspection and checkout operations or large space stations and interplanetary vehicles became evident.

A prototype leak detector was designed, built, and tested. The instrument is basically a hand-held, self-powered, ion pressure gauge designed to operate in ambient pressures below 10^{-4} torr. Linear pressure measurements by the pressure detector (General Electric trigger gauge) are transformed into logarithmic electrical signals by the instrument electronics which are displayed as a deflection on the readout meter. Leaks are detected by noting changes in pressure when the trigger gauge is placed in close proximity of a leak. Since these changes in pressure are apt to be quite small, the meter pointer movement is more likely to be discernible when operating the instrument at low ambient pressures. Therefore, when searching for leaks, the instrument, upon actuating the buckout switch, simulates a low pressure indication by automatically subtracting an induced electrical signal from the signal which represents the ambient pressure. Electrically, this simulation is accomplished by using current (approximately one ampere per torr) to actuate the trigger gauge during operation. There are two sources of

22 LEAK DETECTOR FOR USE IN SPACE ENVIRONMENT (Continued)

this current; (1) from the logarithmic amplifier which drives the readout meter, and (2) the buckout circuit. As more current is delivered from the buckout circuit, less current is delivered by the logarithmic amplifier and thus the readout meter moves down scale. Buckout is applied in three discrete steps each time the buckout switch is depressed. Therefore, at an ambient pressure slightly larger than 10^{-7} torr, application of the middle level of buckout would also leave the meter sensitive to a small leak signal. However, at 5×10^{-7} torr, the largest buckout level would drive the meter off scale and the 10^{-7} level would reduce the reading to 4×10^{-7} torr, a reading at which a 10^{-8} deflection would barely be noticeable. Thus, when small leaks are to be measured in higher pressures, more buckout levels are needed, e.g., small discrete steps or a continuous buckout adjustment.

23	MANDATORY NASA INSPECTION REQUIREMENTS	Ref. Code A

PURPOSE: Hardware inspection techniques.

In the beginning of the Saturn program, hardware inspection was conducted on a surveillance system, the extent of inspection being determined mainly by the discrepancy rate in a particular area. However, it soon became apparent that a determination should be made of those critical characteristics whose failure could cause mission failures and that a heavy concentration of inspection should be focused thereon. Mandatory NASA Inspection Requirements were conceived for this purpose. To begin with, heavy coverage was instituted in most areas until such time as critical manufacturing and inspection procedures and processes were verified. Gradually, as these procedures and processes were proved, mandatory government inspection was decreased until, at the present time, an absolute minimum set of requirements has been established. The Mandatory Inspection Requirements fall mainly into three categories:

(1) Inspection of critical structural operations and alignments.

(2) Inspections to ensure maintenance of contamination control requirements.

(3) Witnessing of testing operations on items whose failure could cause loss of life and/or mission failure.

Mandatory Inspection Requirements for the latter category are determined mainly by the analysis of failure mode and effects documents and test procedures in selecting those test facets that are critical to mission success.

23	MANDATORY NASA INSPECTION REQUIREMENTS (Continued)

Requirements for the first two categories are determined by the application of engineering judgment in selecting those characteristics during assembly and alignment operations thought to be critical to mission success.

It is felt that these concepts of mandatory inspection are directly relatable to any aerospace program that may arise in the future. In order to be even more effective, however, it is recommended that the critical characteristics be identified during the very early stages of the program, i.e., during the initial drawing review. Having been designated on the drawings, these characteristics could then be incorporated into manufacturing and inspection planning from the outset.

24 MASS DROP-OFF MEASUREMENTS BASED UPON PRECISE PRESSURE AND TEMPERATURE MEASUREMENTS

Ref. Code G

PURPOSE: For detection of leaks in complex gas systems on space vehicles.

An analytical study was performed to determine if Mass Drop-Off measurements, based upon precise temperature and pressure measurements, could be used successfully for the detection of leaks in complex gas systems on space vehicles.

The study showed that this technique could be used to detect leak rates to an accuracy of 1 scim on systems less than 5 cubic feet in capacity, but only if the temperature in the system is uniform and constant throughout the entire volume during the checkout period. This is based upon a minimum detectable pressure decay of 0.1 psi/hr. The magnitude of the detectable leak rates become proportionally larger in larger system volumes.

This leak detection technique becomes very ineffective if the temperature environment is not controlled and free of temperature fluctuations and gradients. Under these circumstances, this method could still be used for the detection of very large leak rates or to obtain a general check of the overall status of a closed complex gas system.

24 MASS DROP-OFF MEASUREMENTS BASED UPON PRECISE PRESSURE AND TEMPERATURE MEASUREMENTS (Continued)

Dry air was used as the test media throughout this study, but the same limitations described herein would apply to any compressible fluid.

In the course of this study, it was determined analytically that the technique of detecting leaks with the MD technique is very effective, provided that temperature requirements can be accurately maintained but very limited in scope if the temperature requirements cannot be maintained.

25 MASS SPECTROMETER LEAK DETECTOR TECHNIQUES

Ref. Code G

PURPOSE: For external testing of tankage, including weld seams, bosses, etc.

Although helium mass spectrometer leak detectors have been in use a long time, little is known about their application to aerospace hardware problems. Therefore, an investigation was undertaken to develop and evaluate techniques suitable for testing aerospace hardware for external leakage.

Four basic fixture approaches were developed and proven. These were: One-piece rigid, two-piece rigid, non-reusable (tape), and reusable soft.

A. RIGID FIXTURES

1. One-Piece Rigid Fixtures. It is useful for spot checking areas on flat or spherical surfaces and can be used to test bosses, covers, etc., if there is no extension such as an electrical lead or pressure tubing leading away from the area under test.

The basic fixture design is that of a hat section with a connection for the mass spectrometer suction line and a flange for sealing. Two seal techniques proved useful. On flat surfaces, the best method is a large flat rubber gasket laid on top of the hat section. This rubber should be about 1/8-inch thick, soft, nonporous, and lightly greased with a vacuum grease compatible with the

25 MASS SPECTROMETER LEAK DETECTOR TECHNIQUES (Continued)

hardware under test. This approach is preferred to a gasket between specimen and fixture, as it will accommodate fairly severe surface anomalies such as welds, etc., as long as the discontinuity is not too sharp for the rubber to conform to. The gasket is pulled down and held in place by the vacuum. The fixture should have radial grooves on the bottom of the flange to permit rapid evacuation under the gasket to initiate the seal.

This sytem cannot be used when there is an appreciable curvature in the surface mating with the fixture, so an alternate system was developed. In this case, the soft rubber gasket is placed between the fixture and the test articles. This system allows the same fixture to be used with a wide variety of curvatures; however, the tolerance for discontinuities is limited to what the rubber itself can accommodate in compression.

In both cases, an investigation was made to determine if more sophisticated seals would be more useful. Bonded seals, molded lip seals, and O-rings were investigated and all were found workable in some situations. However, each was more limited in application, and for general application, the two techniques described above had a wider application and will meet almost all needs. In addition, the soft rubber gaskets are inexpensive, easily cut on site, and therefore do not require a large complex inventory of many parts in many sizes.

25 MASS SPECTROMETER LEAK DETECTOR TECHNIQUES (Continued)

2. Two-Piece Rigid Fixtures. A problem not solved by the fixtures described above is the case where a tube must emerge through the fixture. This is the case where a pressure line emerges from a boss, or where a fitting in a line, such as a tee or union, must be checked. A two-piece fixture was developed to perform this task. The seal is accomplished by designing the fixture to mate well, with dowel pins to maintain alignment, and the actual seal is accomplished with a vacuum putty, such as Apiezon sealing compound Q.

Attempts were made to build reusable seals so that putty would not be needed; however, this was not accomplished. Investigation and consultation revealed that a vacuum seal of this type had not been built, and probably could not be built. The basic problem, (as had been discovered earlier) was the "Y" intersection of the mating surfaces where the split in the fixture meets the tube emerging through it.

The putty-sealed fixture works well and can be applied quickly, with test data obtained in 5 minutes or less, achieving full machine sensitivity. However, it is recognized that the techniques are messy and at best adds a cleaning problem and would be unacceptable in certain clean room conditions.

B. SOFT FIXTURES

1. Tape Techniques. The first method developed is a tape technique. The basic approach is to cover the area to be tested with a flexible spacer to provide a passageway for leakage and then seal with a pressure-sensitive, adhesive-coated, plastic tape. A small plenum chamber is placed in the middle of the run and the mass spectrometer connected via suction cup and hose.

This method was successfully demonstrated with tape lengths up to 20 feet. However, it was found to have several drawbacks: (1) if a leak is indicated, then its location must be determined by a series of bracketing maneuvers, halving the area each time until the leak is localized to where the size area to be repaired is reasonable; (2) all tapes act as a semipermeable membrane and extract helium from the air in significant quantities. This ranges from no problem to a serious problem, depending on the length of the taped section and the sensitivity desired. A 20-foot strip of Mylar tape selectively extracted enough helium to indicate a leak of 5×10^{-9} sccs. Therefore, if full machine sensitivity is desired, a dummy strip must be made up and placed near the actual location to use as a reference zero. By this means, a 1×10^{-10} leak can be routinely detected.

2. Reusable Soft Fixtures. This fixture is in essence an elongated suction cup which easily conforms to curved surfaces and can accommodate reasonable discontinuities such as intersecting welds, etc. This fixture works very well and routinely delivers full machine capability in the 10^{-12} range.

26 MILLING OF SPRAY FOAM INSULATION — Ref. Code. B

PURPOSE: To provide a standard thickness of protective coating.

After spray application of the foam material over metal surfaces, the foam surface is very irregular, thus requiring extensive machining to reduce the insulation to the specified thickness and contour. Since the foam is a relatively soft material, it can be cut or trimmed with nonmetallic tooling which will lessen the possibility of damage to the metal surface in the event the cutter should penetrate the foam. Therefore, nonmetallic tooling was developed from high density laminated material such as "hercu-Lam" to accomplish the milling operation.

Tooling of this type was needed to reduce or eliminate the damage caused by metal cutting tools. Several such incidents occured whereby severe damage was inflicted to the metal surface by the metal cutter penetrating the foam.

27 NEW METHODS FOR STAGE PROPELLANT TANK PROOF TESTING — REF. Code G

PURPOSE: Use of high-density slurries as pressure-transmitting media in hydrostatic tests.

The objective of this research program was to develop high-density slurries suitable for use as pressure-transmitting media in hydrostatic testing of stage propellant tanks. This included a determination of the range of densities that could be obtained, determination of compatibility with stage and stage component materials, and the definition of pumping, storage, and other handling techniques.

Water-based slurries were formulated from a large number of materials and it was conclusively shown that specific gravities from two to six could be achieved with readily available materials and conventional chemical processing equipment. Lead oxide (litharge) was shown to be the most suitable material for producing stable slurries over a wide range of specific gravities. Laboratory data indicated that these slurries also act as pressure transmitting media. Additional studies are desirable in order to evaluate more fully and to improve the corrosion characteristics of the slurries when in contact with aluminum alloys.

A preliminary economic analysis favors the construction of an on-site plant for producing slurries in quantities of up to one million gallons. Additional prototype and pilot-plant studies are recommended, however, before construction of a plant is undertaken for large-scale production.

28	NONDESTRUCTIVE TEST DEVICE FOR EVALUATION OF 3/4-INCH THICK POLYURETHANE SPRAY-ON FOAM INSULATION (SOFI)	Ref. Code G

PURPOSE: Application of the sonic impedance method.

Described is the technical survey, research, development, and applications engineering effort performed to develop a nondestructive test (NDT) for the evaluation of the cryogenic insulation used on the Saturn. This insulation is of the low-density polyurethane foam type and is applied by a spray-on technique to the exterior of the liquid hydrogen tanks of the Saturn V vehicle.

The insulation is designed to preclude excessive heat transfer between the atmosphere and cryogenic liquid fuel. Hence, the SOFI must be free of voids in accordance with limits defined by specification requirements and must bond to the aluminum tank skin in a manner adequate to prevent loosening and spalling during stage ground tests or actual flight conditions. In addition, existing unbonds must not be extensive enough to cause spalling as a result of "cryopumping" during the thermal extremes of tanking and detanking operations.

The first step in the selection of a NDT technique was an evaluation of the pertinent SOFI properties and the existing quality requirements. From this information a sound basis for consideration or rejection of a test method was formed. A detailed technical survey of various NDT techniques was then performed. Based on strong theoretical evidence, a vibrational impedance method was selected and a prototype impedance head was fabricated, improved, and evaluated.

28	NONDESTRUCTIVE TEST DEVICE FOR EVALUATION OF 3/4-INCH THICK POLYURETHANE SPRAY-ON FOAM INSULATION (SOFI) (Continued)

The evaluation was performed on coated and uncoated test panels containing preplaced voids and unbonds at 3/4 inch depths, coated test panels with preplaced unbonds at 2.0 inch depths, uncoated test panels with preplaced voids at 2.0 inch depths, and uncoated 3/4 inch test panels with no known defects.

The sonic impedance method was capable of detecting unbonds and voids with minimum dimension of 1.0 inch in 3/4 inch SOFI. The minimum gap or defect thickness dimension of detectable defects was established to be 0.003 inch on test panels containing natural occurring unbonds.

The sonic impedance method demonstrated an ability to locate defects smaller than specification limits and is recommended for NDT evaluation of cryogenic SOFI for the following reasons:

1. It can be operated manually or in an automated system.
2. The readout or flaw discrimination is made by an electrical system (meter and recorder), instead of complete dependence upon the the operator's ability.
3. It can detect unbonds and voids in 3/4 inch insulated structures after the polyurethane protective coating has been applied.

29 PIECE PART SAMPLING/ANALYSIS FOR SUBTIER SUPPLIERS

Ref. Code A

PURPOSE: Hardware quality analysis.

The intent of this inspection program is to allow the major contractor to reach beyond the first level of suppliers and randomly sample those suppliers' procured components and hardware. Detailed attention is given to those "piece parts" (individual components or small assemblies procured by the supplier) which could adversely affect the quality level and/or operation of the suppliers' hardware.

The prime significance of this method is that it provides, via randomly selected parts from existing stores, an analysis of the quality level of the subtier suppliers' hardware. This concept further provides an evaluation of the affected first-level suppliers' documentation and control systems for procured hardware.

The costs of operation for this technique are nominal but when viewed in perspective of the results which can be attained, the operation becomes even more economical. The concept of source control can be extended to selected subtier suppliers at a small fraction of the cost for comparable results which could be anticipated from such programs as those encompassing personal visits by quality field representatives.

30 PRECISION MEASURING ROOM

Ref. Code D

PURPOSE: Provides environmentally controlled conditions for precision measurement.

An environmentally controlled precision measuring room with the latest precision measuring equipment was fabricated and put into use to support development and production of hardware which included dimensions which must be machined to a critically close tolerance.

31 QUALITY ASSURANCE ROTARY INSPECTION TABLE

Ref. Code A

PURPOSE: Provides a 34-foot diameter rotating inspection table.

The 34-foot diameter rotating inspection table, in conjunction with stationary optical measuring equipment, serves as a uniform reference standard for dimensional measurements, and provides a single, central, established (permanently set up), means for performing complete dimensional analysis (angular and linear) and critical dimensional inspections of large complex assemblies for the Saturn V booster stages. The rotary table, in itself, provides a uniform reference standard or optical comparator for each major section of the booster.

The size of the rotary table (34 feet in diameter) was required to accommodate the large sections of the Saturn booster (33 feet in diameter) such as the thrust structure, intertank, forward skirt, tank skin rings, Y-rings, tank head assemblies, etc. These sections and/or smaller structures can be inspected on the rotary inspection table under optimum conditions for inspection purposes. The utilization of a single reference plane eliminates the inherent variations of the multiple table system. Such variations are not always predictable and could appreciably reduce the accuracy of the mathematical computations required for vertical assembly of these major sections.

31 QUALITY ASSURANCE ROTARY INSPECTION TABLE (Continued)

The rotary table, aside from being a single reliable reference plane, also provides a degree of accuracy unattainable when movable optical equipment is used. The fixed position of the optical equipment in relation to the rotation of the inspected item further provides another uniform reference plane by eliminating or at a minimum, greatly reducing the error factor induced by changing the plane of reference of the inspection equipment.

It is highly probable that an inspection system such as the one used in the Saturn program can be significantly improved further in accuracy, time, and ease in making dimensional measurements and analysis, for application to future programs by utilizing laser measuring equipment in place of, or in addition to, optical equipment in conjunction with the rotary inspection table.

32 QUALITY DATA REPORTING SYSTEM	Ref. Code A

PURPOSE: Comprehensive evaluation and reporting of trend data.

The Quality Data Reporting System is a means for the systematic and comprehensive evaluation and reporting of quality trend data and determining those areas that required special inspection emphasis.

The system functions as follows:

1. Contractors' Q.C. System Evaluations are performed primarily by elements of NASA Quality Engineering and Reliability to ensure that the contractor has established, implemented, and is maintaing a quality control system which satisfies all contractual requirements. Formal surveys are conducted on a scheduled frequency based on nature of function.

2. Production Verifications are inspections performed on hardware to applicable drawings and specifications established by design. In the verification effort, documents were designed and implemented into a system for reporting, in specifics, all activity. The reports used provided data on shakedown discrepancies and area survey checksheets. All of this information is identified as to area in the factory, and trend charts are maintained to determine areas that have a large number of problems.

32 QUALITY DATA REPORTING SYSTEM (Continued)

This system replaced a prior method which did not provide for a counting of items inspected that were satisfactory. The prior method was capable of counting only deficiencies against contractors. The new method counts good and bad inspections, thus, a percent discrepant rate is established, i.e., one out of 10 bad or 10 percent bad. The system can thus give a good measure of quality (even when volume of work is a variable).

The system was needed to place priorities on a limited amount of NASA inspector's and engineer's time and to begin working on the most important problems first.

This system can be valuable on any program since it is an effective and efficient management tool.

33 RADIOGRAPHIC THRESHOLD DETECTION LEVEL OF SUBSURFACE CRACK-LIKE DEFECTS IN ALUMINUM WELDS

Ref. Code G

PURPOSE: Defines the detection capabilities in quantitative terms with respect to crack length, width, and depth.

Several penetrameter designs are used throughout the industry as technique indicators to measure the radiographic quality level or evaluate those parameters influencing the ability to measure radiographic sensitivity in quantitative terms. The designs are presently based upon the ability of an experienced film interpreter to resolve radiographic images produced by drilled holes, wires, tapered and parallel slits, and spheres.

Of prime interest in this program is the ability of a given radiographic technique to resolve small weld cracks and to define the detection capabilities in quantitative terms with respect to crack length, width, and depth. The closest approximation to the configuration of a naturally occurring weld crack which has been achieved to date is the taper or parallel slit technique used by several investigations to study the limitations of radiography in detecting crack-like defects. In the slit technique, cracks are simulated by placing two identical machined shims next to each other, and by varying the arrangement and thickness of the shims, various slit dimensions (simulating width and depth of cracks) can be obtained and the minimum detectable slit size can be determined for any given radiographic technique. The limitations of simulating the configuration of a crack with machined rectangular shims are obvious, and one important variable which cannot be reproduced by this method is

33 RADIOGRAPHIC THRESHOLD DETECTION LEVEL OF SUBSURFACE CRACK-LIKE DEFECTS IN ALUMINUM WELDS (Continued)

the irregular shape of the edges of the crack. Another serious limitation which is peculiar to this test program is the ability to satisfactorily machine flat, square, and parallel edges on extremely thin sheet or foil.

Because of the above-mentioned limitations on employing slit-type penetrameters, it was proposed that a closer approximation of a natural crack might be possibly achieved by initiating and propagating a fatigue crack in a SEN-type specimen (single-edge notched) similar to the configuration used in fracture mechanics studies. A fatigue crack prepared in the SEN specimen, although not representative of a natural weld crack, would be a much closer approximation of a natural crack because of the irregular fractured edges and irregular crack pattern produced during propagation. This method of simulating a natural crack, therefore, was proposed as the principal technique with the tapered slit technique to be used as a backup or alternate method. In both techniques, it was felt that the simulated crack dimensions (width, depth, and length) could be readily controlled or measured to obtain reliable and reproducible data regarding the minimum threshold detection level for any given radiographic technique and material thickness.

To satisfy the requirement of determining the detection capabilities of internal or subsurface weld cracks for a specific radiographic technique, a penetrameter with predetermined crack or slit dimensions (width, depth, and length) can be sandwiched between the welds of two test plates previously machined from the test material under

33. RADIOGRAPHIC THRESHOLD DETECTION LEVEL OF SUBSURFACE CRACK-LIKE DEFECTS IN ALUMINUM WELDS (Continued)

study. Finally, by employing several of these plaque-type penetrameters, whose crack or slit dimensions are graduated and fixed in terms of width, depth, and length and sandwiching them between matched sets of welded test plates, the vanishing point of the slit or crack for each penetrameter can be determined by experienced film interpreters. Thus, with a specific set of penetrameters as described above and applied to a given material, material thickness, and radiographic technique, crack width (w) and crack depth (d) can be plotted to establish the minimum crack dimensions which are discernible under a given set of test conditions. These test data then provide a reliable and reproducible reference for either establishing or maintaining a satisfactory radiographic quality level for detecting internal crack-like weld defects. It is important to note that these special penetrameters were not to be designed to judge the type or size of weld cracks or to establish limits of acceptability.

34. REMOTE VISUAL INSPECTION SYSTEM

Ref. Code G

PURPOSE: For inspecting areas not accessible for direct viewing.

The purpose of this project was to develop a visual inspection system and techniques for inspecting areas not accessible for direct viewing, such as the inside of valves and lines installed on a flight vehicle. The parameters within the system developed included:

1. Portability - System was to be compact and flexible enough to permit easy transportation by one or two people in a common vehicle such as a pickup truck or large car.
2. High image resolution - System was to be equal to the present inspection devices or about 40 paired lines per milliameter.
3. Permanent image retention - Permanent image retention was to be either photographic film or video tape.
4. Operator ease of operation - System was to be capable of entering close places on space vehicles and still be efficiently operated for long periods of time without undue physical strain on the operator.

The different phases of the investigation included mirror systems, rigid borescopes, the newer flexible fiberscopes, closed circuit television, and light supplies.

A review of the preceeding systems led to the development of a system mating the flexible fiberscope with the closed

34	REMOTE VISUAL INSPECTION SYSTEM (Continued)	34	REMOTE VISUAL INSPECTION SYSTEM (Continued)

circuit television system. This was done by using the standard eye piece or ocular lens assembly to project the image of the item under inspection. It is a general practice to add an adapter lens between the fiberscope or borescope and the film or television cameras. The addition of this lens cuts down the available light at the film plane or on the vidicon tube of a television camera. The adapter lens also cuts down on the total system resolution. As a means of overcoming these two problems, the ocular lens of the fiberscope was modified so it projected a 5/8 inch diameter image at a distance of 4 inches from the eye piece of the fiberscope. The lens modification was accomplished by spacing the final lens assembly approximately 5/16 inch beyond its original position on the fiberscope. This can be easily done by loosening a set screw and relocating the eye piece or replacing the eye piece with an adaptor lens. Utilizing the ocular lens or eye piece of the fiberscope as a projecting lens required an adjustable extension tube to keep external light from reaching the face of the television camera vidicon tube. Also, a mounting fixture was designed to hold the television camera firmly and correctly align the eye piece of the fiberscope with the vidicon tube. It was necessary to keep this unit as small as possible, so it could be carried into physically restricted areas of space vehicles. Instead of mounting the television camera on the fiberscope support, the vidicon tube and its electronic yoke control assembly were removed from the main camera body and mounted directly on the fiberscope ocular end support bracket. The assembly was electrically connected by an adapter cable to the main camera body and its controls. The camera was in turn connected to two other units. The first unit was a Model RCV 17 Conrac TV monitor with an inherent resolution of 500 lines. The second unit was a video distribution amplifier which could feed the video signal to another communications building where the image and audio could be permanently recorded or sent out over a television distribution system. This system can be used in many areas of inspection, design, and failure analysis. The technology used to design this system could be applied to improving existing units in the medical profession for use in space medicine, i.e., measurement of organ movement during launch conditions.

The project produced an operational television-fiberscope inspection system which is available with an operator for "on call" service.

The system consists of:

- o A Sylvania 800 series camera with 800 line resolution.
- o A Conrac Model 14 TV monitor with about 500 line resolution.
- o An American Cystoscope Maker's Light Supply Model 1000 containing a 150-watt lamp and a 1000-watt mercury vapor lamp.
- o A fiberoptic light supply with a 150-watt lamp.
- o Two American Cystoscope Maker's Model BFO-3864-DD fiberscopes; one has a 1/8 to 1 square

34 REMOTE VISUAL INSPECTION SYSTEM (Continued)

inch field size and 1/4 to 1 1/2 inch focus capability and the other has a 2 square inch to over 10 square foot field with a focus capability from 1 to over 10 inches. Both fiberscopes are 72 inches long, have remote focus of the objective lens, and have remote position control of the final 6 inches of the tip.

The system is mounted in modular sections on a standard laboratory cart, weighs 220 pounds, requires 20 amperes at 110 volts, and can be loaded into a car or light truck by one or two people.

The remote visual inspection system needs further research and development in the areas of illumination, use of ultraviolet light with the fiberscope, and color rendition and transmission through fiberoptics.

35 SOLENOID TESTING BY ANALYZING ELECTRICAL TRANSIENTS

Ref. Code G

PURPOSE: Plotting of a current rise versus time curve.

When an electrical solenoid magnet is energized with a direct current voltage, a characteristic rise of electrical current is generated in the windings of the solenoid. This current change may be plotted as a current rise versus time curve. The electrical and mechanical characteristics of the solenoid coil and the motion of the solenoid plunger determine the characteristics of the derived curve.

Previous studies of the current curves of solenoid-operated mechanical devices indicated that the characteristics of the curve could be related to mechanical characteristics of the solenoid and the operated device. It was believed that the curve could be used as an operational signature for the device; therefore, an analysis of the curve parameters might provide an improved tool for determining the operational quality of the device. Furthermore, not only existing quality but gradual degradation might be detected which would make it possible to use this technique for failure prediction.

From the tests performed, the accuracy of the time measurements was limited by a small variation in the Visicorder timing lines and by the large time interval of 0.01 second. No two intervals were exactly the same due to motor speed variations. The timing over a number of intervals was obtained by averaging the interval and using a rule with equal intervals as determined by the average. Also, the intervals of 0.01 second were spaced almost an inch apart and required a proportional method to determine a time ending between the intervals. Another problem was

35 SOLENOID TESTING BY ANALYZING ELECTRICAL TRANSIENTS (Continued)

that the timing line did not synchronize with the application of voltage to the solenoid. This synchronization is required to start the interval being proportioned.

The preceding problems can be eliminated by the use of a marker that is controlled by a stable oscillator. The oscillator is divided down to obtain the desired intervals of time and applied to another recording channel on the Visicorder.

Two recording channels could be used to provide markers on each side of the recording paper to give a means of drawing in a timing line. These intervals of time could also provide the delay times and turn on signals required for automatic control. These signals would synchronize the energizing of the solenoid with the markers on the recording paper. This marker system would be highly flexible and would cover the range of any solenoid.

A stable oscillator with the divider network was designed and fabricated. This system provided an accuracy of less than 1 millisecond over a room temperature change of 30°F. The divider network provided markers at 1- and 10-millisecond intervals. The designed marker system was used for tests after the tests were performed in the first test report. The time measurements using this system were more convenient than the previous averaging and proportional system. A general test system is proposed using basically the measurement used in these tests and the marker system to provide the

35 SOLENOID TESTING BY ANALYZING ELECTRICAL TRANSIENTS (Continued)

instrument control signals. A range of current measurement would be provided by switching in different current shunts. Any calibration range could be obtained by using plug-in modules for the DC amplifier. Several plug-in sections with a selection switch could be used for convenience. The plug-in modules could be fixed gain to reduce calibration requirements or variable gain to provide flexibility in testing. The only difficulty expected in this system is the DC drift which can be reduced by the use of appropriate DC circuitry. A system that is more automated, requiring less technical knowledge, could be developed by using digital techniques. The Visicorder and current measurement circuits may be replaced by a counter. The counter would count time from solenoid turn on to the minimum current point draw (T_2). There is no difficulty anticipated in developing this test system. The T_2 point can be easily detected because of the steep wave front that has consistently preceded the T_2 point. The detection of the T_2 point will require the development of a stable triggering circuit that would be independent of solenoid type.

The implementation of subject technique would provide an improved tool for checkout, adjustment, and failure prediction of solenoid-operated mechanical devices. Checkout of the device may be accomplished by comparison of variations of curve parameters with defined acceptable limits for the variations. Adjustment of the solenoid may be accomplished to reduce the curve parameter variations to a minimum possible value from defined nominal values.

35 SOLENOID TESTING BY ANALYZING ELECTRICAL TRANSIENTS (Continued)

Failure prediction may be accomplished by comparison of parameter variations with known initial parameters. Failure analysis requires an extensive analysis of combinations of parameter variations in order to pinpoint the exact cause of present or incipient failures. In some cases, it may not be practical to identify the exact cause or causes of present or incipient failures.

Any complete failure, excepting a leakage failure, can be detected by this technique. The test technique is sensitive enough to detect degradation of all types of failures that may be expected in a solenoid before complete failure. In some cases, the test results predict the cause of failure, but cannot predict when the failure will occur. This technique shows improvements of accuracy, increased failure information, and test speed over the present test techniques.

36 SOLID-STATE RADIOGRAPHIC IMAGE AMPLIFIERS

Ref. Code G

PURPOSE: Replacement for fluoroscopic screens and X-ray film.

The developed radiographic amplifiers are intended as equivalent or improved replacements for fluoroscopic screens and X-ray film used in radiographic evaluations of space vehicle components and structures. Light sensitive storage amplifiers were developed as potential replacements for "X-Y" type area scan-recorders, when used with a light intensity point light source input.

Radiographic storage amplifier screens (8 x 10 inch size) were fabricated both on glass substrates and on plastic substrates. They were built in a simple photoconductor-electroluminescent (PC-EL) sandwich type construction with ZnO as the sensing material. The minimum exposure for obtaining an acceptable image on these screens was about 1 roentgen. The resolution was 300 to 500 lines/inch (6 to 10 line pairs/mm). The storage time was (to 1/3 brightness) between 5 minutes to 1 hour, depending on the preparation of the ZnO and on other construction parameters. The erasure of the image was achieved by heating the panel in a furnace or by electrical heating of a panel electrode. It needed 1 to 10 minutes depending on the storage time of the panel.

The nonstorage higher sensitivity panels similar to fluorescent screens, were constructed in a PC-EL sandwich structure also, but the PC layer was sintered CdS-CdSe powder. Threshold sensitivities were lower than 60 mR/Minute (1 mR/sec.).

36 SOLID-STATE RADIOGRAPHIC IMAGE AMPLIFIERS (Continued)

The contrast sensitivity of both types of radiographic amplifiers closely approached the 2 percent thickness definition per MIL-STD-453, for 0.25 inch thick aluminum plate (2 percent penetrameter outline visible).

Light sensitive storage panels were successfully developed. The two different approaches which evolved were: (1) using a nonstorage PC-EL image intensifier (CdS-CdSe) in combination with a Thorn image retaining panel; (2) using a light sensitive ZnO photoconductor in a simple PC-EL sandwiching construction.

Promising experiments were made by sandwiching a non-storage radiographic amplifier panel with a light sensitive storage panel of the ZnO type. Also, experiments with photographic film exposure in contact with a solid-stage radiographic amplifier improved the contrast sensitivity. One approach to meet reasonably high requirements would be by integrating in one unit two cascaded image amplifiers.

37 SPECIAL BORE SCOPE TECHNIQUE

Ref. Code A

PURPOSE: Provides 360° fish-eye view of the interior of lines.

Special bore scopes for inspection of the interior of installed propellant supply lines have been developed.

The borescope provides a 360° fish-eye view of the interior of the lines.

This scope was developed to inspect for contamination in offset areas within propellant supply lines similar to shelf-like offsets caused by the larger diameter of bellows within the line.

38 SPECTROPHOTOMETRIC ANALYSIS — Ref. Code A

PURPOSE: Chemical analysis of cleaning solution concentration.

The concentration of cleaning solutions for LOX and fuel tanks is being determined by comparison to standard solutions. This determination is done by spectrophotometric analysis of the test solution versus the calibrated standard solutions.

Because the previous method, chemical analysis, was relatively slow and tedious, the spectrophotometric system was developed which appreciably reduced the time factor and increased the overall accuracy.

The previous chemical analysis required the evaporation of the chemicals being tested to a given volume which was time consuming. In the spectrophotometric method, the chemicals can be used in their normal state, therefore, eliminating the time required for evaporation and the loss of chemical value.

39 STANDARDS DESCRIBING AND ESTIMATING LEAKS IN AEROSPACE HARDWARE — Ref. Code G

PURPOSE: Standardization of leakage rate determination using the bubble technique.

Bubble size is primarily a function of two parameters, size of air passage and air velocity; other factors such as temperature, etc., have very little effect.

Each size leakage passage has a characteristic minimum bubble size which prevails from the smallest observable flow, up to the flow rate at which air velocity becomes the governing factor. When air velocity becomes the governing factor, bubble size gets progressively larger and less uniform, until the air velocity becomes so high that no bubbles can form.

The minimum leak that can be reliably detected is approximately 0.001 scim (standard cubic inches per minute). This is approximately three bubbles per minute on threaded AN flare fittings and the formation of a patch of milky-white foam about the size of a match head on a flanged fitting in 1 minute.

Highly skilled observers can detect lower leak rates under ideal conditions but the limit of 0.001 scim is used as the lower limit as it can be detected routinely by properly trained personnel under usual field conditions.

Air passage size, as discussed above, is the basic parameter governing bubble size from minimum leak, up to the point at which air velocity governs. Most threaded flare fittings have the same order of magnitude thread clearance and, at low flow, all leakage past the flare

39 STANDARDS DESCRIBING AND ESTIMATING LEAKS IN AEROSPACE HARDWARE (Continued)

escapes by this route, unless blocked by excessive thread lubricant.

This commonality of thread clearance passages explains the characteristic small uniform (approximately 1/64 to 5/64 inch diameter) bubbles that occur and persist on threaded flare fittings. As the flow rate increases, a definite point is found where air velocity causes larger bubbles of random size to form and persist, although for a shorter time. A second distinct change occurs at some higher flow where very large bubbles form that are short lived.

Flanged fittings exhibit an entirely different behavior at low flow rates. The characteristic leak through a flanged fitting is a number of very fine hair-like leak paths and results in very small bubbles which, through a defraction phenomenon, often appear as a milky-white foam within the liquid detection agent and may build up like a deposit of shaving cream lather.

At higher rates where air velocity is the governing parameter, larger bubbles of random sizes occur as in the threaded fitting.

Fifty-five samples (11 each of 1/4, 3/8, 1/2, 3/4, and 1 inch) of flared tubing connectors were tested to obtain quantitative values for transition flow rates. It was found that the spread on all sizes was very similar for each transition and that a meaningful pattern emerged.

39 STANDARDS DESCRIBING AND ESTIMATING LEAKS IN AEROSPACE HARDWARE (Continued)

It is concluded that fitting leaks can be divided into types and classes as described, and the approximate flow rates can be estimated as follows:

	Threaded Type	Flange Type
Class I	0.001 to 0.4 scim	0.001 to 1.3 scim
Class II	0.4 to 2.8 scim	1.3 to 4.0 scim
Class III	2.8 to 47.0 scim	4.0 to 50.0 scim

With experience, an observer can further refine the estimate within Class I of both types, especially at the low end, by observing buildup per unit time.

For threaded fittings, each Class I bubble is usually 1.3 x 10^{-4} cubic inches. Therefore, a bubble count for 1 minute multiplied by 1.3 x 10^{-4} will give an approximation in scim.

For flange Class I leaks, the volume of accumulated foam after 1 minute can be estimated for approximate flow rates.

40 TEST ASSESSMENT PROGRAM

Ref. Code A

PURPOSE: Validation/revalidation of system functions.

The cessation of testing of a system or the removal of any member of that system, whether during or after completion of a test, has always initiated some degree of suspicion regarding the integrity of that system. The Test Assessment Program, designed to meet the needs of the Saturn test program, addresses the validation/revalidation effort to be "real-time" and continuous in nature. An assessment of a tested system is performed immediately before and after testing. The pretest assessment is designed to determine if any constraints exist which might adversely affect the tested system. The immediate post-test assessment designates whether any unplanned events which occurred during the specific system test have caused invalidation of that system or of previously tested systems.

This program has proven the feasibility of performing a continuous audit function as an adjunct to major test activities. Details of operation would require revision to conform to specific program requirements, but the basic concept can be realistically applied for major test activities of any future programs. Furthermore economy of operation can be realized since the amount of research work required to ascertain the integrity of a tested system can be reduced considerably.

41 THRUST CHAMBER LEAK CHECKS

Ref. Code D

PURPOSE: Provides a sealed cavity inspection area for inspection of thrust chambers.

In order to perform leak checks of tube-to-tube braze joints for thrust chambers, a special leak test pit was designed. This pit provided a means to support a thrust chamber in an inverted position with a sealed cavity surrounding the external portion of the thrust chamber. This cavity could then be pressurized and a leak check made internally of tube-to-tube braze joints.

42	TOPOGRAPHICAL RECORDER	Ref. Code A

PURPOSE: Measurement of irregular surfaces.

When the necessity exists to provide continuous recordings of measurements to define the extent of alignment and/or mismatch, the time factor reaches such a magnitude that serious schedule delays can be anticipated and an automated system is mandatory.

The topographical recorder system provides an accurate, efficient, and cost optimized technique for the inspection of welded seams. The recorder, by means of a comparator stylus, is capable of providing an alignment determination and comparison, and a visual display of these measurements as a one step operation. The visual display is in the form of deviations from a reference line on a strip chart recorder. The strip chart provides a permanent record of the inspection and the actual values of the measurements. As the name implies, the recorder is also capable of providing an exact determination of the topography of concave or convex "cans" which might occur on a bulkhead surface of the propellant tanks.

This technique appears to be readily adaptable for any pressure vessels which would require inspection of welded seams.

43	TORQUE WRENCH CALIBRATOR	Ref. Code D

PURPOSE: Precision to ± 0.5 percent of reading.

A torque wrench calibrator was designed, built, and placed into service. This equipment is a unique advancement in the state-of-the-art in that it is accurate to ± 0.5 percent of reading in a usable range of 5 to 4,000-foot pounds. This is five times more accurate than commercially available equipment. This equipment was necessary on the Saturn program because of the necessity to provide torque wrenches within required accuracies.

44 ULTRASONIC DELTA TECHNIQUE FOR ALUMINUM WELDS AND MATERIALS

Ref. Code G

PURPOSE: Rapid scanning weld inspection for penetration and fusion.

The Delta Technique is a unique, multicrystal inspection method that is relatively insensitive to defect orientation. Internal weld defects including lack of penetration and lack of fusion were readily detected when using this technique. This technique is capable of rapid scanning rates while providing a simultaneous and permanent record of the test results.

Test demonstrated that the Delta Technique successfully detected the weld defect of primary concern in 2014 and 2219 aluminum alloy weldments at inspection rates of 50 feet per hour. Lack of penetration of a 0.030 inch x 0.060 inch size and lack of fusion as narrow as 0.025 inch were reliably detected by the Delta Technique. Microfissuring, a laminar shrinkage type defect found in 3/16 inch and 1/4 inch weld sections was detected by the Delta Technique where radiographic techniques failed because of unfavorable defect orientation.

Correlation of the nondestructive tests was made by destructively analyzing 18 feet of weld for total defect content. Findings of this study show that for a quantity of weldments containing tight lack of penetration up to 80 percent of the total defects were detected by the Delta Technique while only 36 percent of the total defects were detected with radiography.

44 ULTRASONIC DELTA TECHNIQUE FOR ALUMINUM WELDS AND MATERIALS (Continued)

A manual Delta probe and a Delta wheel assembly were fabricated in Phase II of this program. An evaluation of these Delta configurations was made by inspecting 168 inches of aluminum butt weld, sectioning the welds, and comparing the correlation percentages with those obtained in the development of a Delta weld inspection for aluminum welds (Phase I). Both the Delta wheel and the manual Delta probe provided the same quality of weld inspection obtained in Phase I.

45 ULTRASONIC IN-PLACE TUBE WELD INSPECTION SYSTEM

Ref. Code D

PURPOSE: Inspection of tube welds.

This system was designed for inspecting critical in-place tube closeout welds on hydraulic lines. It is capable of inspecting closeout welds ranging from 0.250 to one inch in diameter and weld cross sections of 0.020 to one inch. Some unique features of the system are the split lucite rings which serve as the transducer positioner and also act as a couplant dam. A vernier assembly provides precise indexing of the transducer during the manual scanning of the weld. The miniaturized components permit ultrasonic inspections to be performed with limited access to welds or space adjacent lines.

46 ULTRASONIC TECHNIQUE

Ref. Code A

PURPOSE: Detection of metal faults.

Ultrasonic inspection techniques have been refined or developed to provide for:

a. Detection of surface cracks due to stress corrosion
b. Detection of cracks in thin (0.090 inch) aluminum sheets
c. Inspection of installed electrical feed-through connectors for detection of O-ring grooves.
d. Determination of actual fusion diameter of spot welds.

47 ULTRASONIC TUBE ANALYZER SYSTEM

Ref. Code D

PURPOSE: Inspect and measure thickness of tubes.

The ultrasonic tube analyzer system that was developed was the first such system in the country which had the capability of ultrasonic inspecting and performing thickness measurements on both straight and tapered tubing ranging from 0.125 to one inch in diameter and resolving material discrepancies as small as 0.002 inch in depth. This inspection can be performed at inspection speeds of 40 feet per minute. The rotating head is equipped with two transducers, one to detect circumferential defects and one to detect longitudinal defects. The information from the transducers is transferred through a capacitance coupler to a receiver and the results recorded on a strip chart recorder.

48 UNIFORM REFERENCE STANDARDS

Ref. Code A

PURPOSE: Clarification and definition of Class I documentation.

Due to the nature of the various processes associated with the fabrication and installation of electrical components, assemblies, cable routing and tubing, ducting, and piping installations, difficulties arise in achieving uniform interpretation of acceptance criteria.

A system of Uniform Reference Standards was therefore established. The Uniform Reference Standards provided reference standards to clarify and further define existing Class I documentation and specifications. For example, wire or cable routing is seldom spelled out in Class I documentation as to length, configuration of bends, method and spacing of supports, and other aspects only derived after mock-up fit, etc.

This effort resulted in the production of the following documents:

a. Uniform Reference Standards for Inspection of Electrical Assemblies and Components

b. Uniform Reference Standards for Inspection of Electrical Installations

c. Uniform Reference Standards for Inspection of Tubing, Ducts, or Piping Installations.

By being collected into book form, the reference standard can be made available to all personnel within manufacturing

48 UNIFORM REFERENCE STANDARDS (Continued)

or assembly areas. Since the book format makes graphical and/or descriptive narratives immediately available at the point of need, i.e., the solderer's bench, the inspection station, etc., it is not necessary for individuals to attempt to maintain a "memory picture" of a correct assembly. Since visual images tend to become more and more a matter of individual interpretation with the passage of time, the uniform reference technique further provides a constant refresher course for the correct procedures which were learned during the formal schooling phase of the training cycle.

49 USON LEAK DETECTOR

Ref. Code D

PURPOSE: Detector for use on all helium supported systems.

The Uson leak detector which was developed as a result of the overall Saturn program proved very useful. The use of this device allows use of helium as the pressurizing medium without a tracer gas and a Halogen leak detector. Since helium is the control medium for most pneumatic systems and the use of helium provides a more sensitive leak detection method than gaseous nitrogen, reliability was enhanced by utilization of the Uson leak detector.

50 VACUUM PLATE INSPECTION TECHNIQUE FOR CORK DEBONDS

Ref. Code B

PURPOSE: Verify the structural integrity of sheet cork insulation.

A nondestructive inspection technique has been developed to verify the structural integrity of sheet cork insulation in the vicinity of the LH_2 feedlines on the Saturn vehicle. The capability is required primarily to detect any cork/foam debonds that may have occurred as a result of static firing of the stages. The objective is to provide assurance that the cork insulation is structurally sound prior to CDDT at KSC, and describes the inspection device and provides operating procedures for inspection personnel.

The inspection technique consists of the application of a tensile load, by vacuum, to the cork/foam composite while measuring the amount of induced deflection of the cork. Cork debonds, as small as two inches in diameter, will display a marked increase in deflection compared to structurally sound areas.

51 VOLUMETRIC GAS FLOW MEASURING TECHNIQUE

Ref. Code A

PURPOSE: Use of alignment optics and a closed T. V. system.

Volumetric gas flow readings are being taken by using alignment optics and a closed T. V. system. This technique is 25 percent faster and more accurate than the previous technique, which used two men, allows direct reading, and requires only one man for operation.

52 WELDING PROGRAM

Ref. Code A

PURPOSE: Precertification for the welder and process.

Assurance was required that the Saturn welding program would, in fact, produce reliable weld joints on all weldments. This problem was approached in several stages which are listed below:

1. Weld Certification
   a. Process certification
   b. Operator certification
      (1) Manual welder
      (2) Machine operator
   c. Certification status of weldment
   d. Equipment calibration and control
2. Welding Evaluation Program
3. Weld Motivation Program
4. In-Process Control of Weld Variables

The program was designed to establish a means of implementing the applicable specifications to a program that would ensure ultimate reliability.

52 WELDING PROGRAM (Continued)

The system involved precertification requirements for the welder and the process. A training program was established for welders and also a weld development program for weld processes. Criteria were established to evaluate results and a system of records reflected the progress.

TECHNICAL MEMORANDUM TM X-64574

APPROVAL

RETENTION AND APPLICATION
OF SATURN EXPERIENCES
TO FUTURE PROGRAMS

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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